Engineer INNOVATION

Issue 8

Science-fiction becomes science-fact

Not everyone is a science-fiction fan, but I would guess quite a lot of engineers are. Not just the science-fiction of early 20th century literature but also late 20th century film culture. Space travel, flying cars, a voice-controlled world… many of the innovations proposed by this genre has become not merely fiction but fact, and in this issue of Engineer Innovation our customers are delivering the dream of yesterday for tomorrow's reality.

We have been sending satellites into space for decades, but now we can fly them using more sustainable methods with reduced environmental and economic impact, Reaction Dynamics (RDX) showcase their new technology here. Sticking with aerospace, 'Why wheels are important on planes' seems obvious, but the landing gear of the Wright Brothers Flyer is fundamentally different to that developed by Safran Landing Systems used on today's planes. Hint: The Wright Brothers didn't use wheels.

Even the ultimate symbol of summer holidays, the ice-cream, has been improved with the aid of engineers' innovation although I don't recall ever reading or watching ice-cream transformation in any science-fiction.

Sustainability is at the heart of the Simcenter ethos, efficient fuel production and optimized consumption are the cornerstone of a more sustainable future. In this issue we also examine the many colors of hydrogen production and what impact this can have on fuelling the future. And to deliver the future, we need engineers of the future. We spoke to Remi Duquette, Vice President of Innovation and Industrial AI at Maya HTT to hear how they are nurturing the future generations. Because it wouldn't be science-fiction without a touch of Artificial Intelligence.

À bientôt,
Jean-Claude

Contents

"You may have the universe
if I may have Italy."

Giuseppe Verdi

From ICE to Ice Creams

How Internal Combustion Engine (ICE) technology makes better gelato

By Prashanth Shankara

Home of alluring art, incredible history, heavenly food, stunning landscapes and phenomenal fashion, Italy epitomizes life in all its lazy, elegant brilliance. Italy is 'La Dolce Vita' – "the sweet life" – a life of heedless pleasure and luxury.

This story is a surprising marriage of two Italian things that best symbolize heedless pleasure and luxury – supercars and gelato. This is a story of how a small Italian company, well-known for their expertise in super car Internal Combustion (IC) engines, helped an ice-cream manufacturer make better gelato.

Made in Modena, Italy

Our story starts in Modena, the 'City of Engines'. This charming Italian town is also the unofficial 'supercar capital of the world'. Ferrari, Lamborghini, Maserati, Pagani and Bugatti all call Modena home.

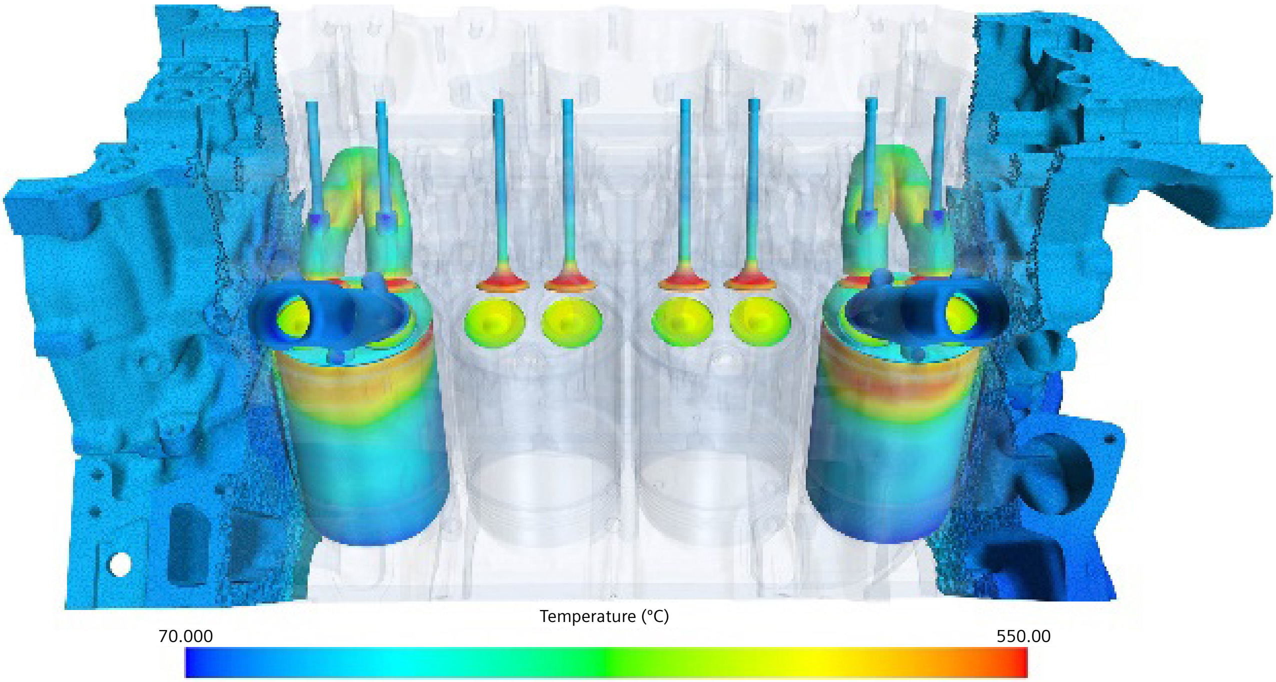
It is here, that Giuseppe Calise, a graduate of the nearby University of Modena and Reggio Emilia, established R&D CFD in 2012 with his Professor, Dr. Stefano Fontanesi. Borne out of the University's Internal Combustion Engines (ICE) research group, they do engines well. Really well.

The CFD in their name is a nod to their expertise in computational fluid dynamics (CFD) simulations. R&D CFD works with most of the supercar manufacturers around Modena helping them build better IC engines digitally using CFD simulation.

IC engine operation is complex. Combustion of air and fuel, temperatures of 4500 F (2500 C), moving pistons, hundreds of chemical species, and thousands of reactions some of which occur in a billionth of a second. All of this inside a small, dark cylinder, inside a fast supercar. How do you analyze such complexity? How do you find the best engine design?

With CFD, companies like R&D CFD build a digital engine. Every process in and outside the engine is digitally modeled, analyzed and visualized. Add in design optimization and you can evaluate hundreds of scenarios and designs digitally before building anything.

First left:
Modena, Emilia Romagna, Italy. Piazza Grande and Duomo Cathedral at sunset.



First right: Simcenter STAR-CCM+ simulation showing thermal behavior of engine components, courtesy R&D CFD

In 2019, their CFD simulation and engineering expertise caught the eye of an unlikely customer: a leading Italian gelato manufacturer.

The variegated gelato

The global ice-cream market is worth $80 billion USD and increasing every year. Nearly 80% of the ice-cream sold is machine-made, either to take home in a box or consume immediately. It's a massive market.

The manufacturer who worked with R&D CFD is famous for their variegated gelato. Excuse the fancy word here! A variegated gelato is merely ice-cream with a sauce swirled into it – chocolate, strawberry, caramel, fruit, peanut butter and more (Now I'm getting hungry).

Chasing the good (looking) gelato

Ice-cream was once a dessert for kings. But thanks to capitalism and mass production, the common man can enjoy one of life's greatest delicacies. Our gelato maker was one such mass producer. Gelato in a box was their specialty. With years of mass-producing experience, the taste of their gelato was world class – creamy, rich and dense.

Good gelato needs to be good-looking. No one likes a dull, rough, garish looking ice cream. Eating ice-cream is an emotional, evocative experience. In a competitive market, the look and feel of your gelato makes all the difference. The manufacturer's list of requirements for esthetically pleasing variegated gelato was long: soft, smooth, silky, elastic, and of natural color. Improving the look will have a direct impact on sales and customer satisfaction.

"The customer wanted our help to predict how their variegated ice-cream would look at the end of their manufacturing process. People who buy this ice-cream are looking for a certain hand-made feeling. But how do you make it look hand-made in a machine?", says Giuseppe.

A simpler design; a better swirl

The secret lies in the variegator. This machine mixes the ice-cream and the sauce, fed through different pipes. Their current variegator was a static one with no moving parts. But the design was complex. The ice cream and sauce came in contact with screws, baffles and walls. It was hard to control the sauce pattern or mixing. It was exposed to air, a strict no-no for good gelato. The number of parts meant cleaning the variegator thoroughly was difficult to do.

The ice-cream maker found a simpler design. Just two concentric cylinders, one each for the ice-cream and sauce and a nozzle connecting the two. They mix directly in the variegator: no screws; no baffles; or interaction with walls. Just simple, straight mixing. Easy to clean, better to control mixing and a more beautiful sauce swirl into the ice-cream. In theory, the new design was perfect.

Improving the variegator with CFD simulation

Now they needed to make the design better. They needed to predict how the ice-cream would look after manufacturing before being stored in boxes.

This is where R&D CFD's simulation and design optimization experience came in handy. They had Simcenter STAR-CCM+, a CFD Multiphysics software and Simcenter HEEDS, a design optimization software, both tools from Siemens' Simcenter portfolio. For years, they used Simcenter STAR-CCM+ on supercar engines to understand the flow and thermal behavior of engines. Simcenter HEEDS helped them analyze the performance of hundreds of designs and scenarios.

The simulation technology used to design supercar engines was now being applied to gelato making.

"We decided to use our engine simulation tools to improve the variegator design. With digital simulation, we could reduce making prototypes and save time and cost in design. It also helps us analyze hundreds of designs", adds Giuseppe.

2,000 designs; one perfect sauce swirl

"Simulating ice cream and sauce is not so simple as simulating air and water", says

First left:
Good variegation

Second left:
poor variegation

Seriously, which one is more appealing?

Alfonsina Esposito, CFD engineer at R&D CFD. "They are gooey, viscous, elastic fluids. Understanding the rheology and thermal behavior took some time".

Simulating these visco-elastic fluids with CFD is challenging. With Simcenter, they could model such challenging physics, thanks to a Volume of Fluid (VOF) multiphase and rheology model. The software was able to model the ice-cream, sauce, and the interface between the two accurately.

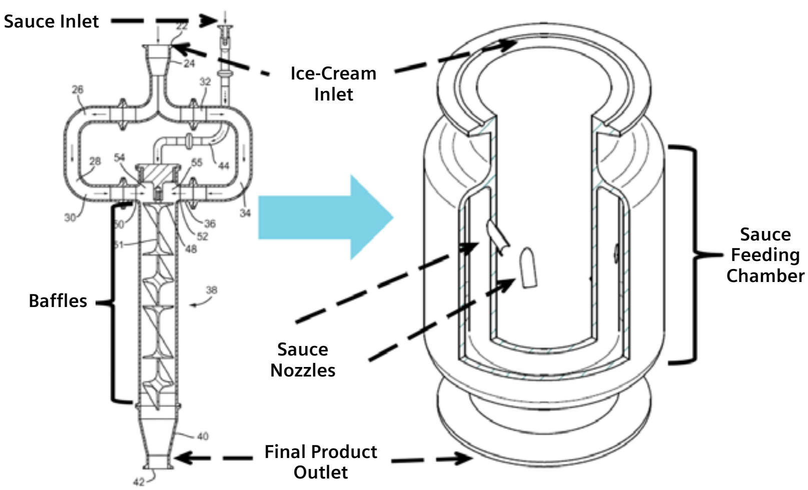
"In the past, we worked with other simulation software where the process was way more difficult. What we enjoy with Simcenter STAR-CCM+ is the variety of physics you can simulate, from engines to ice-creams", adds Alfonsina.

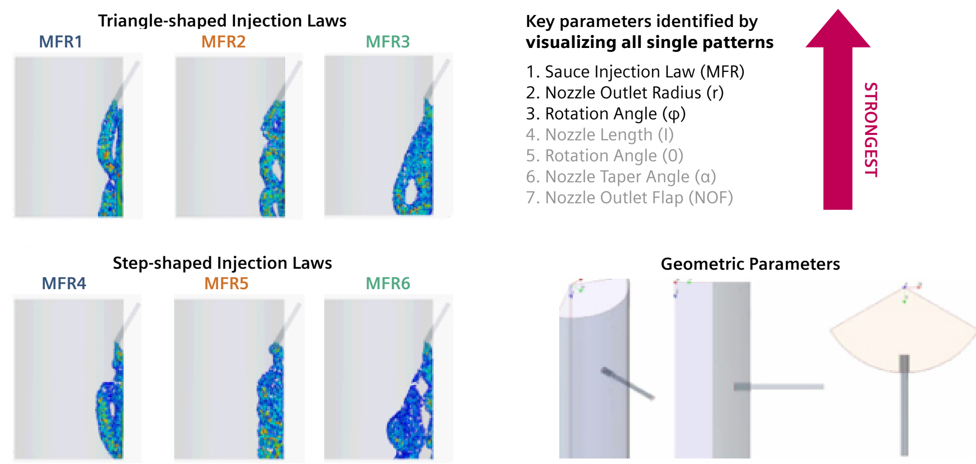
Using Design Manager, a technology within Simcenter, Alfonsina modeled 2,000 different design scenarios changing the nozzle geometry and operational physics laws to inject sauce. The software automatically found the design that produced the best sauce pattern and swirl.

Imagine having to build and test 2,000 different variegators instead!

80 designs; best variegation

For mass production, the variegator needed multiple nozzles for faster operation. All these nozzles need to be fed the same quantity of sauce from the feeding chamber. This way, the ice cream in every box was identical in appearance and texture, ensuring customer satisfaction.





Alfonsina used Simcenter to automatically analyze different geometries of the sauce feeding chamber and the resulting sauce distribution. After analyzing 80 designs, the best feeding chamber design was found. Now all the nozzles receive the same amount of sauce. Mass production of perfect gelato activated!

“It’s so fast to do automation and optimization with Simcenter HEEDS or Design Manager”, adds Giuseppe.

You can see how the optimized design gives the same, beautiful swirl to the sauce from every nozzle compared to irregular patterns from the initial design.

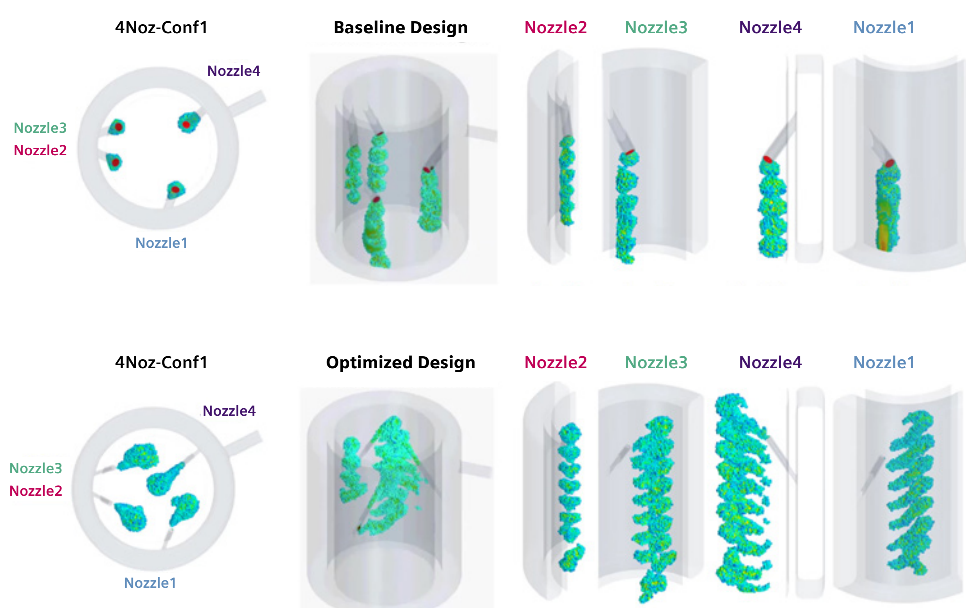
From ICE to ice-creams

R&D CFD’s improved variegator design is now in use in all the manufacturing plants of the customer. As predicted with simulation, the variegation is top-notch.

The team at R&D CFD experienced something unique – eat something they helped engineer.

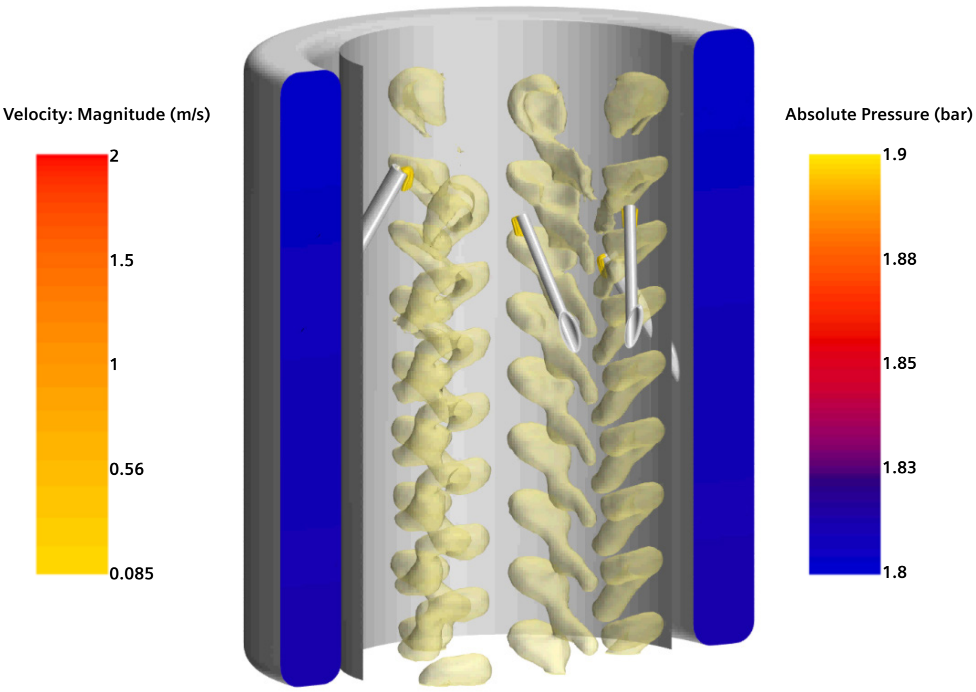
“I’ve tried the ice-cream and I’m very appreciative of the job done. Looks delicious. Tastes delicious”, a smiling Alfonsina reports back.

“We live and breathe internal combustion engines (ICE). We never thought we’d be working on making better gelato”, adds Giuseppe. “With Simcenter, we have gone from ICE to ice creams”. ■



First left:
Video showing different nozzle designs to find the design giving the best sauce pattern and swirl

Second left:
(Top) Baseline design showing poor variegation and irregular sauce pattern from four nozzles (Bottom) Optimized feeding chamber design giving similar swirl pattern and better variegation from all nozzles.



Postscript:

- It was a chilly Amsterdam winter when I interviewed Giuseppe and Alfonsina for this story. Throw in our Sicilian cameraman and I felt like an honorary Italian for a good 30 minutes.
- I might have spent a little too much time looking at pictures and videos of ice-cream for this story. The neighborhood ice cream parlors now know me on a first name basis.
- I know you want to try this gelato. Unfortunately, we cannot name the manufacturer. But this is reason enough for you to try all the Italian gelato brands and report back.
- I have successfully managed to write about ice-creams without mentioning that wretched Vanilla Ice song even once (It rhymes with 'Rice Rice Maybe')

First right: Beautiful swirl pattern of sauce from CFD simulations was replicated in the new variegators built by the manufacturer.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Black, Gray, Blue, Purple, or Green

What color is our low carbon hydrogen future?

By Stephen Ferguson

Energy is the only universal currency. Since the beginning of the Industrial Revolution, the human race has become increasingly dependent on the cheap and plentiful supply of energy. It feeds us, lights our evenings, fuels our movements, keeps us warm in the winter and cool in the summer, and provides endless piles of disposable "things" that we use as a temporary substitute for happiness.

The problem is that currently, about 87% of that energy comes from the combustion of the decomposed remains of ancient organisms (natural gas, crude oil and coal). Hydrocarbons are cheap and plentiful and are (not surprisingly) principally made from various combinations of carbon and hydrogen atoms.

During the combustion process, the carbon atoms combine with oxygen atoms in the atmosphere and produce copious amounts of CO_2, which is a greenhouse gas, which we have belatedly discovered is the principal cause of climate change. Unless we stop burning hydrocarbons pretty quickly, our species will cause permanent catastrophic damage to our planet.

So why don't we just cut out the carbon and burn pure hydrogen instead?

The good news

Hydrogen is the most abundant chemical substance in the universe, constituting roughly 75% of all normal matter. Our own sun is 75% Hydrogen and 25% helium.

Hydrogen is about three times as energy-dense as natural gas (which is principally methane) and more than twice as energy-dense as gasoline. Burning hydrogen is much cleaner than burning hydrocarbons. When mixed with pure oxygen it only produces water as a by-product of combustion.

Unlike hydrocarbons, which we typically have to burn in heat engines to produce electricity, hydrogen can be used to generate electricity directly, and at much higher efficiency in fuel cells, again producing only water as a by-product.

The bad news

Although hydrogen is the most abundant chemical substance, hydrogen gas does not occur naturally in large quantities on Earth (although obviously, the element is present in the planet's vast supplies of water). Hydrogen is the lightest of all elements, and any hydrogen gas that does enter the atmosphere quickly escapes the Earth's gravity into outer space.

This means that if we want to use Hydrogen as a zero-carbon fuel, we first have to manufacture it. At the moment most of the economically viable processes are far from "zero-carbon". In 2021 so-called "Green Hydrogen" just doesn't exist.

Black and gray hydrogen

In 2021 about 96-98% of hydrogen is produced from fossil fuels, either through coal gasification (black hydrogen) or natural gasification with steam methane reformers (gray hydrogen). Unfortunately, both of these processes result in the emission of large quantities of CO_2, which somewhat defeats the purpose of hydrogen as a low-carbon synthetic fuel. Gray hydrogen accounts for most of the production today and emits about 9.3kg of CO_2 per kg of hydrogen production.

Globally, 6% of natural gas and 2% of coal is used in hydrogen production. As a consequence, the production of hydrogen is responsible for CO_2 emissions of around 830 million tonnes of carbon dioxide per year, equivalent to the CO_2 emissions of the United Kingdom and Indonesia combined.

We also don't make very much synthetic hydrogen; only around 120 million tonnes a year are produced, only two-thirds of which is pure hydrogen.

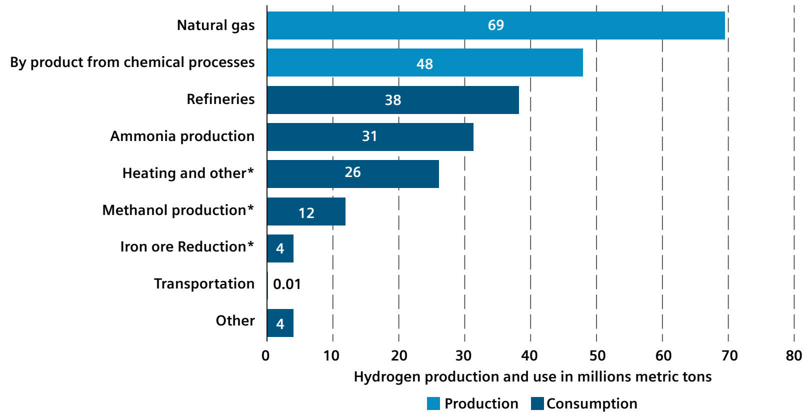
Clearly black and gray hydrogen are not a solution to the climate crisis.

Blue hydrogen

Grey hydrogen can be made greener using carbon capture and storage.

The carbon is captured using methane reformers which work by exposing methane to a catalyst (normally nickel) at high temperature and pressure. This is a challenging problem, a high-temperature environment with complex chemical reactions, occurring at a wide range of spatial and temporal scales. These processes are capable of capturing around 90% of CO_2 emissions but are not currently widely deployed for reasons of cost and reduced efficiency. Simcenter continues to be used to validate, and improve carbon capture processes, enabling the production of much lower carbon synthetic hydrogen.

Hydrogen production and consumption worldwide in 2019, by sector (in million metric tons)



Source
Fraunhofer ISE
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Additional Information:
Worldwide; Fraunhofer ISE; 2019

Having gone through all the trouble of capturing CO_2 the next problem is sequestering it permanently. The most likely, in underground geological formations, such as depleted natural gas wells. This is an extensive area of research that Simcenter is playing an extensive role in.

Green and purple hydrogen

As I mentioned earlier, there is one plentiful potential source of hydrogen that doesn't depend on complex chemical reactions and carbon capture. We live on a planet that is 71% covered by water (H_2O). Pure hydrogen (and oxygen) can be extracted through a process of electrolysis, a chemical reaction that occurs when an electric current passed through water (basically an inverted fuel cell).

Clearly, this is a zero-carbon process as water does not contain any carbon molecules. However, a significant caveat is that the electricity used to drive the process must also come from a zero (or at least very low) carbon source. Therein lies the problem, just over a third of electricity production is from low-carbon sources (such as wind, solar, hydro or nuclear). If the energy used to produce your hydrogen is dirty, then the hydrogen is dirty too.

If the end-use of hydrogen is to drive an electric motor (or a combustion engine that could be replaced by a motor) it also doesn't make much thermodynamic sense to use electricity to create a synthetic fuel which will later be converted back to less electricity than you started with.

First Left:
Most hydrogen is produced from methane and is used mainly in chemical processes

However, one of the problems with low-carbon electricity, particularly from wind, and solar sources, is that it is intermittent. There are times when the supply of electricity exceeds the demand, and any electricity generated is essentially wasted. There is significant potential for this energy to be converted into hydrogen, either as a temporary storage medium or for use as synthetic fuel elsewhere.

Currently, green hydrogen is two to three times more expensive to produce than blue hydrogen (partly due to the cost of electrolyzer materials). However, as global efforts to decarbonise power generation progress, the potential for manufacturing plentiful supplies of green hydrogen (from renewable sources) or purple hydrogen (from nuclear) will increase.

However, progress is slow, and in 2020 the Institute for Energy Economics and Financial Analysis (IEEFA) suggested that green hydrogen supplies will only hit 3 million tonnes annually by 2030, short of a projected demand of 8.7 million tonnes.

Increasing the production of green hydrogen depends on managing the complex interaction between different modes of intermittent power supply, which is something that will be managed by digital twin technology. Simcenter has recently been used to demonstrate how a green hydrogen production facility might work.

Storage and transport

Our species has lots of experience in transporting liquid and gas hydrocarbons around the globe.

At the start of this article, I described how hydrogen is three times as energy-dense as methane, and twice as energy-dense as gasoline. However, this is only true per unit mass. Since hydrogen is the lightest of all elements, one kilogram of uncompressed hydrogen occupies 7.3 times more volume than a kilogram of methane. This means that a tank required to store a given amount of energy as hydrogen is much larger than for a hydrocarbon.

Another issue is that hydrogen atoms have the smallest atomic radius of any element in the universe. This means that hydrogen molecules can often migrate through the metal fabric of a storage tank, escaping into the atmosphere.

The solution to both of these problems is to compress hydrogen gas into a liquid state, in which it occupies almost 800 times less space per unit mass. However, in this state, it needs to be kept at a temperature of -241 C - which is a significant engineering challenge.

Safety

Although hydrogen is not a toxic gas, it is a very flammable one. The 1937 Hindenburg disaster is etched forever in the public memory. Hydrogen has a wide range of flammable concentrations in air and much lower ignition energy than gasoline or methane.

In addition, some metals can become brittle when exposed to hydrogen, so the material choice is important in the design of safe hydrogen systems.

In 2019 there were several incidents of hydrogen explosions. Firstly a storage tank at a green hydrogen production plant in Gangneung City South Korea exploded, causing two deaths and six injuries. In California, several hydrogen transporter trucks caught fire and exploded due to a leak of hydrogen. A hydrogen leak also caused an explosion in a hydrogen filling station in Norway.

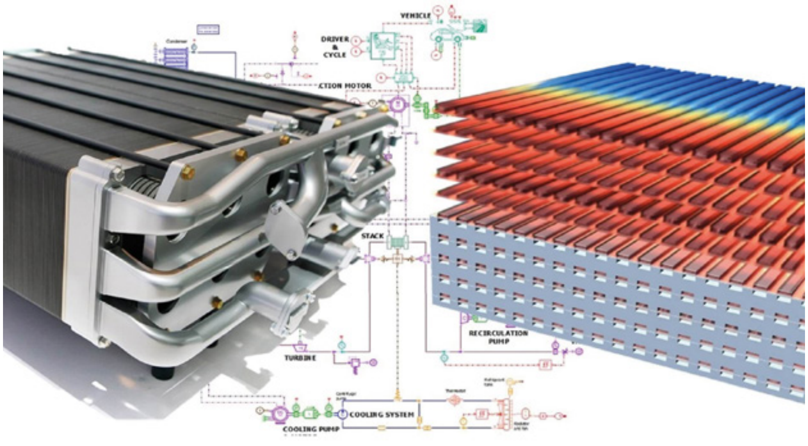
Clearly, much work is needed to increase confidence in a hydrogen economy. Simcenter is used extensively in industrial gas dispersion, quantitative hazard analysis and safety risk management. Simcenter is also being used to design safe hydrogen delivery systems that can be used at vehicle refuelling stations.

Fuel cells

Hydrogen fuel cells are not new technology. Fifty years ago fuel cells provided the electricity (and some of the drinking water) that allowed the Apollo missions to reach the Moon.

Fuel cells combine oxygen and hydrogen to produce electricity. They have no moving parts, are silent in operation, and produce no harmful emissions, yielding only water as a product. They are also highly efficient, with typical efficiencies in excess of 60%, and highly scalable powering everything from laptops to power stations.

Compared with a hydrogen-powered combustion engine (described below) the fuel-to-wheels efficiency of cells is almost double. However, with this considerable promise, and decades of investment, we are yet to see the wide-scale adoption of fuel cell technology in road transportation. Part of the issue is (as described above) hydrogen has a lower volumetric energy density than gasoline. The lack of hydrogen infrastructure



and safety concerns are also a problem. However, it seems certain that fuel cells will have an important role to play in our low-carbon future, and Simcenter is being extensively used to improve fuel cell technology.

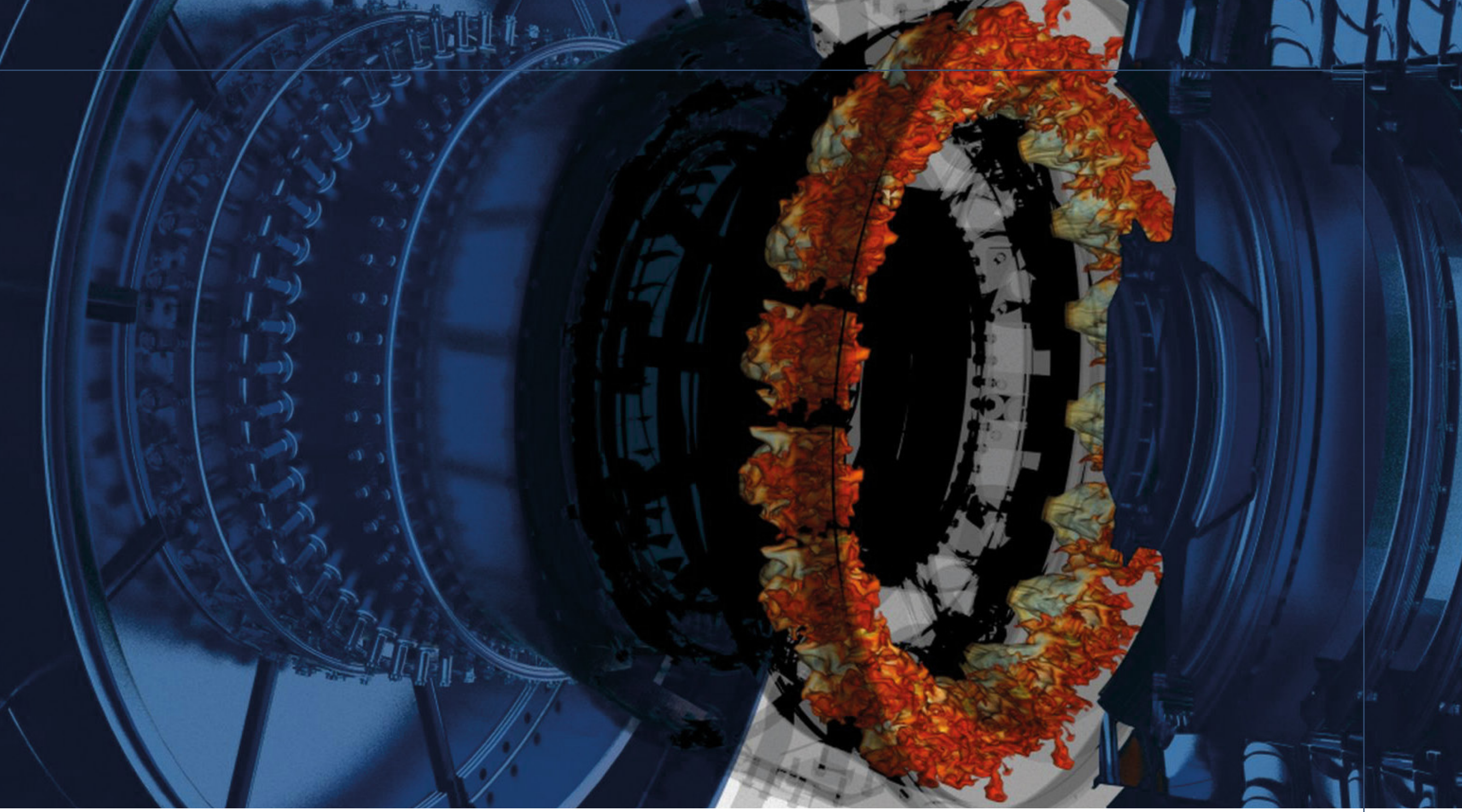
Combustion engines

As the world struggles to transition towards a low carbon future, it seems that the most effective method of reducing emissions is reducing combustion through electrification. This strategy obviously depends on the decarbonisation of power generation, almost two-thirds of which still depends on combustion.

There are two problems here. The first is that the power density of fuel cells and batteries is much lower than for combustion engines. This means that in transportation (which is responsible for 20% of CO_2 emissions) that it is much easier to electrify small things (cars, trains, buses, commuter aircraft) than it is to electrify large things (passenger aircraft, cargo ships, trucks). For the foreseeable future, those things will continue to be powered by internal combustion engines, powered by either biofuels or synthetic hydrogen.

Although engine manufacturers have over 100 years of experience in designing hydrocarbon fuelled engines, there is much work (and extensive simulation) required to make a new generation of reliable greener cleaner engines. Simcenter is already playing a role in that transition.

The second problem is that the rapidly growing supply of renewable electricity is intermittent. Currently, power grids depend on gas turbine generated power to provide the buffer between the "base-load" (mainly



from coal or nuclear), and inherently intermittent renewable power(solar, wind, hydro). Put simply, gas turbines are what keeps the lights on when the sun isn't shining and the wind isn't blowing. Eventually, grid-level storage from either battery or green hydrogen might provide an alternative solution, but for now, our electricity supply is dependent on the combustion of gas.

The good news is that there is no inherent reason why gas turbines have to burn fossil fuel hydrocarbons. Gas turbines are naturally "fuel flexible", so attention is increasingly turning towards so-called synthetic fuels such as hydrogen (H) and ammonia (NH_3). These fuels contain no carbon, and therefore do not emit any CO_2 during the combustion process.

All the world's major gas turbine manufacturers are addressing this challenge by either retrofitting their existing turbine to work on a mixture of methane and low-carbon synthetic gases such as hydrogen and ammonia, or designing new turbines that are more naturally fuel-flexible.

Although this is an effective way of instantly reducing the CO_2 emissions of gas-fired power stations, there are significant problems to solve when using synthetic fuels. The first is the control of toxic NO_x emissions that are a byproduct of all high-temperature combustion processes in the air (rather than pure oxygen). Although turbine manufacturers have managed to reduce these emissions to very low levels in turbines fuelled by natural gas, synthetic fuels produce different flame structures and higher temperatures. The second is that variations in flame dynamics have the potential to create thermoacoustic oscillations that could damage or limit the operation of the gas turbines.

Simcenter is being used extensively to solve both these problems and enable a new generation of cleaner, greener, gas turbines.

An (almost) hydrocarbon free hydrogen future

I've been involved with engineering simulation for almost 30 years, and for all of that time hydrogen power has always been "just around the corner". The reason that this has not happened so far, is that we have continued to rely on plentiful supplies of cheap hydrocarbons, and have not invested enough into solving the various technical challenges discussed in this article. However, as world governments scramble to achieve their 2030 and 2050 CO_2 emission targets, we will shortly need to confront a mostly hydrocarbon-free future. Hydrogen will play a key role in that future, and extensive engineering is the only way we will deliver it. ■

Why wheels are important on planes

Simcenter enables Safran Landing Systems to avoid technical issues and streamline certification

By Jenn Schlegel

The Wright brothers didn't have wheels on their first plane. So why do we?

Here's some food for thought: early aviation pioneers Wilbur and Orville Wright did not put wheels on their first plane, the 1903 Wright Flyer. The famous 12-second flight that took off on December 17th, 1903 from the beach in Kitty Hawk, North Carolina started by launching the flyer into the air using a rail system. The self-taught engineers didn't use wheels or landing gear because, logically, they were taking off and landing in deep sand. Wheels would be problematic, to say the least.

Constructed with spruce wooden frames, unbleached muslin fabric and honestly heaps of tenacity, sheer grit and dreams, the first Wright brothers' planes were all about getting off the ground and into "piloted" flight. Wheels were either for catapulting the early flyers into the air or for moving the Wright Flyers around on the ground. Only in around 1910 did the Wright brothers' planes, the Military Flyer and the Model AB, feature wheels.

But back to wheels and that 1903 flyer. The 1903 Wright Flyer's wheels were actually attached to the rail system itself. The wheels, which the brothers constructed from recuperated bicycle hubs, were part of the dolly on the launch rail track, not the airplane. The wheels ran on a rail, in reality, an 18-meter wooden track running through the sand that launched the Wright Flyers into "flight". A later model, the 1906 Wright Flyer, had wheels as well, but they were removable and only used to roll the aircraft from one spot to the other. They were removed before taking off on the track.

Landing gear: a long way since Kitty Hawk
Almost 120 years later, we have come a long way since removable landing gear and catapulting flight tracks. Think about this: At Kitty Hawk, the first Wright Flyer weighed only 275 kilograms without the pilot, who by the way, flew in a prone position. Today, a big bird like a fully loaded Airbus A380 weighs in around a whopping 575,000 kilograms. Just think of the loads the landing gear needs to handle when landing something this immense. (And just a side note: the A380 usually has four pilots on board for long flights. Two pilots are required by regulators to fly the plane. Unlike, the Wright brothers, they fly the plane seated, obviously.)

The landing gear on an A380 or similar aircraft – as you can guess – is far from recuperated bicycle hubs and home-made rail systems. A sophisticated hydraulic ecosystem in itself, modern-day landing gear systems features innovations the Wright brothers could barely imagine: decentralized hydraulic generation; integrated modular avionics braking algorithms; high-pressure hydraulics at 5,000 psi; titanium integration and integrated logistics support (ILS) – just to rattle off a bit of LG (landing gear) jargon.

With something as complex and mission-critical as landing gear at stake, entire engineering departments (and companies for that matter) are dedicated to perfecting landing gear design and development. And passionate and innovative engineers (just like the Wright brothers) have dedicated their engineering careers to designing reliable, robust, weight-efficient and environmentally responsible landing gears.

One of those engineers is Jérome Fraval, a French systems modeling and simulation method leader at Safran Landing Systems. For those of you not familiar with landing gear engineering per se, Safran is the world leader in design, development, manufacturing and support of landing gear systems.

Jérome Fraval has been a Simcenter user for years and is one of the pioneers in the field of system simulation and landing gear development. Today, he and his team help Safran provide highly sophisticated landing gear systems to a variety of aircraft programs.

Landing gear is certainly not one-size-fits-all

One of the Safran team's biggest challenges

is that requirements vary among customers. And analyzing every single system performance is crucial to perfectly meet the differing expectations of each airframe manufacturer. Safran Landing Systems use two approaches to succeed, in most cases, under tight deadlines. One key to success is the use of simulation and digital twins within the engineering department to virtually anticipate system and component efficiency – long before integration into the final product. The second key to success is to implement standard engineering methodologies and streamline practices to deliver a mature product early in the development cycle.

Safran Landing Systems deploy a common methodology for simulation within internal teams as well as when interacting with customers and suppliers. Very basically, the process starts with developing the landing gear structure, then the wheels and brakes and finally system equipment, such as systems for braking, extension, retraction and steering. Safran Landing Systems designs and manufactures the majority of its key equipment and integrates other small components from hydraulics/electrics component suppliers.

System simulation in model-based systems engineering

Using Simcenter combined with Safran's in-house expertise and experience, acquired over several decades, makes it possible to perform tradeoff studies very early in the pre-design phase of complete systems.

"Today the use of model-based systems engineering is essential in our industry because incomplete knowledge of all the operational cases can lead to an incorrect analysis that originally aims at specifying the component performance, " explains Jérome Fraval, Systems Modeling and Simulation Method Leader at Safran Landing Systems.

He adds, "Virtual integration through the digital twin makes it possible to anticipate the commissioning of our products very early on, even well before the production of the first components, which makes it possible to observe sometimes complex physical phenomena and to adjust, if needed, the product design."

System simulation supports the certification process

Virtual analyses with Simcenter enable Safran Landing Systems to support the overall aircraft qualification process and streamline the demanding documentation process. "We have to demonstrate to the authorities that the system model is valid, using the landing gear digital twin," Fraval says. "This is demonstrated through physical correlation with the model that it is valid. The use of Simcenter allows us to support this entire demonstration procedure and complete documentation requirements."
Read more about Safran Landing Systems and the Airbus A380.

And from the research side of things...

What is wonderful about Siemens and Simcenter is that for every innovative engineer out in the field, like Jérome Fraval at Safran Landing Systems, there is most likely someone in-house working the research side of things. Senior R&D Manager Yves Lemmens, based at Siemens in Leuven, Belgium, is one of these engineers. Yves Lemmens' research activities focus on analysis methods of structures, mechanisms, and systems for automotive and aerospace applications. One area he works in is... landing gear.

Since the days of wooden frames and muslin wings are long gone in modern-day aviation, a key challenge for aerospace engineers, today, is complexity. Yves Lemmens and his team are working on methodology improvements to manage the complex engineering required to successfully develop future aircraft.

He writes in his blog, "Over the years, scientists and engineers have discovered many paths that can lead to better aircraft. However, highly interconnected system architectures increase the complexity and slow down the pace of innovation.

Moreover, multiple dependencies and constraints between components (such as joints and limitations on available space) make the design of mechanical systems even more complex."

Make sure to check out Yves Lemmens' complete blog to explore cutting-edge work, which will certainly impact the aircraft development of the future.

And speaking of future aircraft, things are likely to get even more complex as we enter new frontiers like e-flight and VTOL (vertical take-off and landing) - not to mention supersonic aircraft. The world of landing gears will certainly change again in the not-so-far-away future; Siemens and Simcenter will be there to show the next generation of pioneers the path to safe, secure and super-efficient landing gear. ■

Sign up for a free webinar about Simcenter solutions for landing gears

Read about GKN Aerospace Fokker Landing Gear

Tune into our podcast series: Talking Aerospace Today.

First left:
Wilbur Wright landing an early prototype in 1900. Clearly, landing gear hadn't been invented yet.
Image courtesy of the Library of Congress (USA)

Sand, grit and perseverance:

Hard work, testing and top-notch troubleshooting got the Wright brothers off the ground

First right:
On December 17th, 1903, at precisely 10:35 am, Orville Wright lifted off from the launching rail at Kitty Hawk and flew for 12 seconds at an altitude of 8 feet, landing 120 feet away. The Wright Flyer hit a top speed of 6.8 mph with 34 mph winds. With both brothers piloting, they completed three more flights that day, reaching 852 feet in 59 seconds and a top altitude of 10 feet.

Kitty Hawk is located on the Outer Banks of North Carolina, a series of barrier islands in the Atlantic Ocean. It is the 6th windiest place in the USA. A likely location for the Wright brothers and their first successful airplane flights on December 17, 1903. But what one tends to forget is that this first flight didn't happen overnight. From their beach camp in Kitty Hawk and back home in Dayton, Ohio, the Wright brothers had been experimenting and adapting their flyers for more than four years

The two brothers, Wilbur and Orville Wright, were self-taught engineers and bicycle shop owners from Dayton, Ohio who were obsessed with the idea of "piloted" flight. They designed and built early prototype gliders that they attempted to fly in 1900 and 1901 in Kitty Hawk. Wilbur Wright eventually glided about 100 meters in 1901, but the brothers knew their early prototype was still unpredictable and some of the data they had gathered seemed to be invalid. Disappointed yet still full of faith, they returned home to Dayton and built a wind tunnel to obtain new data and update the flyer design.

In 1902, they returned to the Kitty Hawk camp and the 1902 Wright Flyer completed 600 glides. The brothers were convinced they had graduated from unpredictable glider to working airplane. The 1903 version would feature breakthrough innovation with a lightweight engine and original propeller design.

The 1903 Wright Flyer was heavier than expected, weighing in at 275 kilograms. This was five times heavier than the 1902 version and the brothers weren't sure the engine would be powerful enough to lift the plane off the ground. This is when they came up with the idea of the launching rail system, which gave the plane enough momentum to take off. (Prior to this, helpers from the Kitty Hawk camp just ran carrying the wings of the much lighter gliders to launch them into the air.) ■

From radical idea to reality: Leave it to the Danes

Denmark breaks its own green energy record for the second year in a row and keeps innovating with plans for artificial energy islands and ReliaBlades

By Jenn Schlegel

Last year, Denmark sourced more than half of its electricity from renewable energy. Onshore and offshore wind turbines produced just over 46%, and about 4% of Denmark's renewable energy was solar. 2020 is the second year in a row that this tiny Nordic country exceeded 50% renewal energy usage.

Now, there are a lot of reasons for this green success. First of all, Denmark is a rather windy place so wind energy is going to work. Secondly, they have 8750 kilometers of coastline and ample place to put wind turbines out on offshore wind farms in the North and Baltic Seas. (This way the tiny nation will not be covered in onshore turbines.) And thirdly, the country has a very sustainable mindset and has been committed to wind energy for decades.

True green energy innovators, the Danes built the world's first offshore wind farm in 1991. Today, the country is continually improving wind turbine and offshore technology, including the development of two artificial energy islands in the North and Baltic Seas.

An artificial energy island by 2030
With Europe moving towards renewable energy reliance, increasing offshore wind energy capacity and efficiency has become paramount. As wind energy leaders, the Danish are again at the forefront of technology with their planned energy islands. Acting as energy hubs, these energy islands will be able to pool power from multiple offshore farms and feed the energy directly to several neighboring countries. This shifts the concept of offshore wind farms from unilateral supply to multilateral supply, which is a good thing. At maximum capacity, the islands should be able to power over 10 million homes in several countries and create green hydrogen from sea water to power future shipping, aviation, and industry energy requirements.

Measuring 120,000 square meters in size (that is bigger than 18 standard football fields by the way), the main artificial island, located about 80 kilometers off of Denmark's west coast in the North Sea, will be the largest construction project in Danish history. A second, smaller island has already being planned off Bornholm in the Baltic

> We chose Siemens Digital Industries Software as a partner because they have experience working with digital twin technology in other industries and possess a wide branch of software that can support this development,"
>
> **Kim Branner, Senior researcher and head of section, DTU Wind Energy department.**

Sea, to the east of mainland Denmark. This hub will supply energy to Germany, Belgium and the Netherlands. Both islands will give an enormous boost to the European offshore wind capacity and green energy as a whole.

"This is gigantic," states Prof. Jacob Ostergaard of the Technical University of Denmark. "It's the next big step for the Danish wind turbine industry. We were leading on land, then we took the step offshore and now we are taking the step with energy islands, so it'll keep the Danish industry in a pioneering position."

Improving offshore turbine maintenance and longevity

Energy islands aside, there is a lot more going on behind the scenes in Denmark to keep the Danish wind energy industry on the cutting edge. Another professor at the Technical University of Denmark, Kim Branner, is busy with something really innovative called ReliaBlade.

Offshore turbines are, well, offshore. The good news is that they are not readily visible, not easily heard and can be optimally positioned for the wind. The bad news is that, when something goes wrong, they are hard to get to. Kim Branner and his team recognized a need for a better way to monitor offshore turbines for maintenance purposes. And this is where the ReliaBlade project, a Danish-German joint research project, steps into the picture.

"The ReliaBlade utilizes a comprehensive digital twin to monitor turbines and make wind turbine blades more reliable. That's why it's called ReliaBlade," says Kim Branner, a senior researcher and head of section at the DTU Wind Energy department. "The focus is to make wind turbine blades more reliable by using a digital twin. That was one of the ideas behind establishing this project."

Smart turbine maintenance

ReliaBlade wants to ensure that turbine blades last longer without human interaction or other unforeseen problems. By using a digital twin and sensor technologies when building the blades, DTU Wind Energy can develop condition-monitoring systems to observe the blade structure. The system can alert wind turbine owners of potential problems or damage developing in the blade. This allows the wind turbine owner to either change how they operate the turbine or make a repair decision before the issue becomes too critical. For offshore wind farms, this means scheduling the repair when it is easier – say on a summer day – rather than an emergency intervention during a winter storm.

"With the monitoring systems that can come with a digital twin, you have an opportunity to intervene before it becomes a problem and therefore make these structures more reliable," says Branner.

"We chose Siemens Digital Industries Software as a partner because they have experience working with digital twin technology in other industries and possess a wide branch of software that can support this development," says Branner. "And it's not used so much in the wind energy industry. Some companies have worked with a digital twin for the bearings and gears in the drive train of the turbine, but not for blades. That's unique and of course, an interesting area for us as we work with blades and test blades.

"But it's also a very challenging area because those are some of the most highly loaded structures. It's also a challenge because the goal is it should last 20, 30 years, running on a turbine every day in all kinds of weather. It's a hostile environment out at sea. So it's really challenging to build the systems that are robust and can work in practice."

Denmark has committed to an ambitious 70% reduction in 1990 greenhouse gas emissions by 2030, and hopes to become CO_2 neutral by 2050

DTU Wind Energy performed physical testing in Simcenter Testlab software, 1D simulation in Simcenter Amesim software and virtual channels in Simcenter Testlab Neo software. Read the full technical case study here

Ready for the next green energy revolution

As the Danes start to work on constructing their innovative energy islands out in the North and Baltic Seas, the team behind the ReliaBlade project is taking smart maintenance a step further and showing how advanced digital twin architecture and cutting-edge technology like embedded machine learning methods, automated model updating and vibration-based structural health monitoring can keep the future offshore farms running optimally for decades to come. ■

Some extra reading about wind energy solutions.

https://www.plm.automation.siemens.com/global/en/our-story/customers/zf-wind-power/67899/

https://blogs.sw.siemens.com/simcenter/not-in-my-backyard-how-annoying-is-wind-turbine-noise/

https://www.plm.automation.siemens.com/global/en/our-story/customers/moventas/17048/

Q&A

We spoke to Remi Duquette, Vice President of Innovation and Industrial AI at Maya HTT. We talked about what the training of engineers will look like in the future. How should future engineers be educated? Do we need specialized artificial intelligence or generalized humans?

Well, eventually we're going to talk about the engineer of the future, but I wanted to start off by talking about the engineer of the past. Can you tell us a bit about your background and how you got here?
Well, my background is probably not atypical in terms of engineering. In the 90s I did my engineering degrees and graduated from McGill and University of Toronto, and then went into aerospace engineering. That really was my background. Stayed, of course, for probably about a decade in aerospace engineering, and then moved on to the software engineering world and developed all sorts of funky and fun applications. Now I'm in charge of innovation at Maya HTT, and we develop multiple software solutions for different engineering domains not just space, although we did start in space but we now are developing software for about 12 to 15 different industries with experts in each of them. In the last decade, I really moved on to AI and machine learning as a practice within our company.

And it's changing at a really, really rapid pace, isn't it? Whole swathes of existing skills, like learning to drive, are likely to disappear because they're going to be taken over by AI. Is that what you see is or going to happen?
Well, certainly as you mentioned there, there are some skills that will be made obsolete by some of the new technologies that are emerging. Some are a little bit scary and we'll have to see how they evolve and if it's as rapid as we think it will be, but certainly there will be some rapid change. My nine year old is at a summer camp coding today and it's like, "Well, I didn't have a computer at her age because computers were starting out but not really widespread at the time."

So it's kind of an interesting thought to see, and how rapidly these changes will occur. But yes, I'm certainly bracing for a lot more of those changes and that's why I think the future of engineering is important and a really critical topic to address because the engineers we train today... We can't just overspecialize them on specific technologies as we know those may not be available in five years' time because they keep on changing.

How do you think AI is going to affect future engineers' jobs?
AI is really a technology, a new way of dealing with data and learning from data. Engineers have used data in the past whether it's in controllers, in the manufacturing space, or in operations so it's not really a new topic. It's been made a lot more powerful by the computers that we have and the amount of data we have at our fingertips and are able to process, whether it's from telemetry, real-time telemetry, or additional sources that we can tap into.

I think AI will change engineers in a couple ways. One, in augmenting them and two augmenting their capability. It's going to change the way that we think of a design cycle in engineering, or product design.

Nowadays, that product sends back telemetry back home, so to speak, and tells you new things in the environment that you may or may not have put into your design in the first place. It brings new ways to think about how to intuitively design and put forward some interesting new ways of coming up with amazing new products that we couldn't conceive before. That kind of feedback loop that's a lot more rapid and real-time, gives us engineers more tools and interesting information to process.

Do we think that the engineering graduates today are having the correct training to play a part in this future of engineering?
Well, certainly, and I've been in many interesting discussions and conferences with a lot of people that are teaching our engineers. In the past the focus was really more in problem solving skills and I'm going to call them mathematical skills, technical knowledge and logical reasoning and thinking. As, we look to the future, we're at a crossroad where we grapple with generalization versus specialization.

In a way, an analogy to AI. If you over-train and overspecialize a little model, well, at some point it just does not generalize very well and it can't adapt very well. It's the same thing for training engineers.

If I had told you that we would be contemplating self-driving cars 10 years ago, you would've laughed at me but now we're getting closer and closer to that reality and people are not laughing anymore, and they're investing a significant amount to make it happen. That's really, I guess, the point there on specialization versus generalization of engineers. It's definitely moving from pure mathematics to really adaptive skills that will make you a really good engineer that is able to evolve with the pace of technology and adapt with new technologies as new tools.

There is an argument to say that there is a problem with the sort of engineering current software engineers do, in that you spend your whole career trying to drive the software as much as anything else, and not enough time doing real engineering. Assuming that AI is going to free engineers up to do proper engineering, making decisions, giving insight and not just be "mesh monkeys"; Is that how you see the future going?
I definitely see that as a trend, and certainly AI as a technology does bring those insights that kind of bubble to the surface, those insights that may have been hidden in the data or in the software. Instead of having engineers and humans going through and sifting all of this, they can employ the idea of generative AI programs that will give you the best couple of solutions and then you will apply your engineering judgment to pick the right one. I mean, it's still going to be a probability game where AI brings about what's most probable, and people need to think in a different way in those environments. I do see that trend certainly increasing in the future.

And while we will get some brilliant solutions we will also see some completely unfeasible solutions. We still rely on engineers to spot the things that are completely unfeasible.
It's not just unfeasible but dangerous sometimes. You see it in all sorts of things and that's why AI needs to be understood and harnessed in the proper way. AI, again, is purely and simply a new tool in terms of its power. It's been there in terms of algorithms for machine learning and deep learning has been there for over two decades, in which time we've seen it evolve in some brilliant ways, and not so in others. For example if you look at the data used by social media platforms to train chatbots, it may be deemed as unethical in the way that it uses language.

And not forgetting, of course, that human engineers often make bad decisions, and sometimes you're going to need AI to pick up those decisions, as well.

When we talk about the engineers of the future, actually those are the engineers that we're training today because if you graduate next year, basically you're still going to be working in 2060 or maybe even 2070, by which time the world will have changed completely. We have to start teaching these skills, don't we? I guess it happens naturally, but the future starts now.
It does start now, and actually it starts with even us, you and me. I mean, I graduated two decades ago now, but I keep on learning. Every year I make a point of learning, whether it's small or big, a new skill to put in my arsenal of skills. I hate to kind of quote someone like Einstein but once you stop learning, you start dying. ■

To listen to the full interview, download the Engineer Innovation podcast

"If you over-train and overspecialize a little model, well, at some point it just does not generalize very well and it can't adapt very well. It's the same thing for training engineers."

Remi Duquette, Vice president of Innovation and Industrial AI, Maya HTT

Shooting for the Stars

Launching Satellites with Simcenter

By Luke Morris

Did you know there are currently almost 2,000 individual satellites in low Earth orbit? And this number is expected to increase exponentially as continued miniaturisation in electronics fuels the growth of the small satellite market over the next decade. By 2030 it's predicted that a further 8,600 small satellites (weighing less than 500kg) will have been launched. This equates to a market worth an estimated $42.8B USD, with about 30% going to launch costs, and growth of 22% CAGR.

But to get a satellite into space you need a rocket. And rockets don't come cheap. So how are companies going to launch their satellites at the right time and place whilst keeping costs under control?

Currently, small satellite companies have to book space on a large rocket, tagging along with a big payload. This causes high lead times of up to two or three years and if the main payload has to change orbit, they may have to find another rocket meaning further delays. All in all, it's a frustrating and inefficient process.

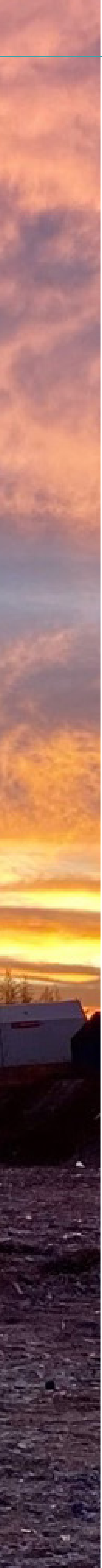
Dedicated launch services for everyone

Reaction Dynamics (RDX) was founded in 2016 by CEO, Bachar Elzein, to address this exact issue. The startup has developed a breakthrough rocket technology that provides the means for an eco-friendly launch solution. Leveraging its breakthrough green hybrid rocket engines, the company's launch technology will pave the way towards clean access to Earth's orbit at a fraction of currently available prices.

Hybrid rocket engines are nothing new – they've been around since the 1930s – but previously they have only been able to run at peak performance for a few seconds. As a result, satellite launch companies have used more complex and more expensive liquid fuelled rocket engines. However, RDX's invention provides better performance over longer duration burn times than any previous hybrid rocket engine – and most importantly, good enough to reach orbit. The propulsion system is much simpler than that of other rocket engines, making manufacturing much cheaper and reliability significantly higher as there are fewer parts that can fail. This also means that vehicle production can be scaled rapidly and, combined with the ease of handling of the propellants, enables a rapid and responsive launch service.

RDX will be manufacturing and operating its own orbital rockets for small satellite launch as a service. Priced at $15,000 USD per kilogram this will compete with other small launch companies as well as some heavy launch companies. The key difference is that RDX provide a dedicated ride at a similar price point to a rideshare on a large rocket. Elzein describes it as "Offering customers a taxi service for the same amount you'd pay for a bus. They can decide exactly when and where their satellites are launched rather than waiting for a rocket that happens to be going in the right direction." The simplicity of the design means the rockets can be built and launched very quickly, enabling rapid response times which would be ideal for the reconstitution of damaged or destroyed military assets in space. With RDX's dedicated small satellite service, customers will have full control over the schedule and can have their satellite in orbit within a matter of weeks instead of waiting up to three years to ride along on a bigger rocket. RDX can always find the correct launch point for the required orbit as they have access to spaceports across the world. And for smaller operators who can't afford a dedicated rocket, their service can be sold to launch brokers who will aggregate small satellite payloads.

So how have RDX managed to design their new hybrid rocket engine which is set to revolutionise the satellite launch industry?



Maya HTT guides the way with Simcenter
Elzein and his team knew they would need the most robust simulation tools, combined with high-fidelity analysis, which is why they engaged with Siemens and Maya HTT. Maya HTT is a Siemens Solution Partner, working with companies like RDX to help them realize the full potential of Siemens Digital Industries Software. Maya HTT's expert engineers enable them to make the most of simulation and virtual prototyping to improve performance, quality, and efficiency, whilst reducing overall development costs.

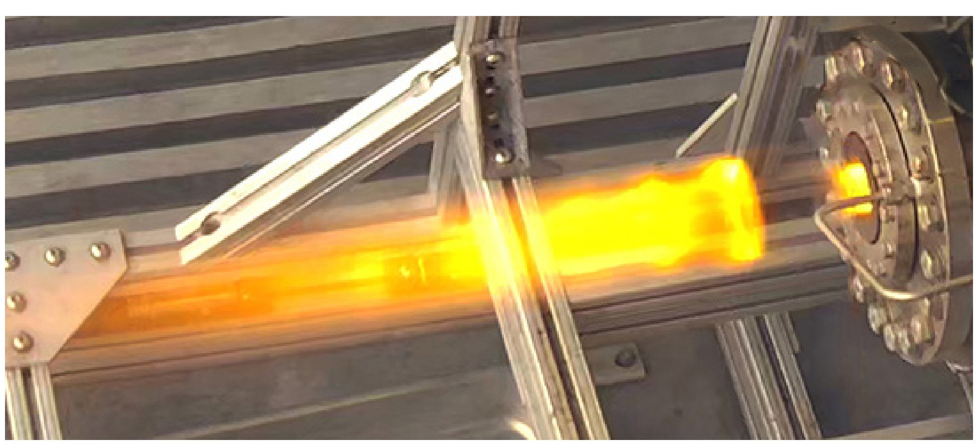
"The quality of the support and the versatility of Siemens' suite of industry software made it a clear winner," says Maxime Goulet-Bourdon, Propulsion Test Lead at RDX. "The integration of so many features within the Simcenter platform means that scaling our simulation capabilities as required becomes efficient and realistic, allowing us to step comfortably into simulations to get the confidence that our designs will respect the applicable norms. Furthermore, the quality of the support received whenever small issues popped up was always great and timely. We know that we can count on the team at Maya HTT to guide and help us through the deployment and adaptation to these new and powerful tools, making us obtain results faster."

Christophe Leclerc, structural design lead at RDX points to CAD integration as a key factor: "For design and analysis, Simcenter is the best option for us, as it enables seamless transition from CAD to simulation, by streamlining the process of simplifying and cleaning up complex design models to prepare the analysis models. This can help accelerate the design process greatly, during which hundreds of iterations can be necessary. Multiple add-on modules, such as the Laminate Composite module, are also available, enabling us to quickly grow our capabilities when necessary,

without having to go through the lengthy process of transitioning toward a new software solution. Being integrated inside Simcenter, also gives us flexibility in our usage, by enabling the creation of an ecosystem where all of our software needs, from CAD to PLM, and including a wide range of simulation tools, are fulfilled by a single platform. For a startup, this ability of the platform to grow with us is of great importance when choosing the best solution."

Elzein says the development of RDX's revolutionary rocket engines would simply have been more resource intensive without Simcenter and they are continuing to discover more benefits from the software: "After switching to Simcenter for the seamless CAD integration and analysis we've been gradually adding more packages and licenses such as Design Explorer and Simcenter Nastran. Each one reduces both our development time and costs as shorter iterations lead to better products sooner."

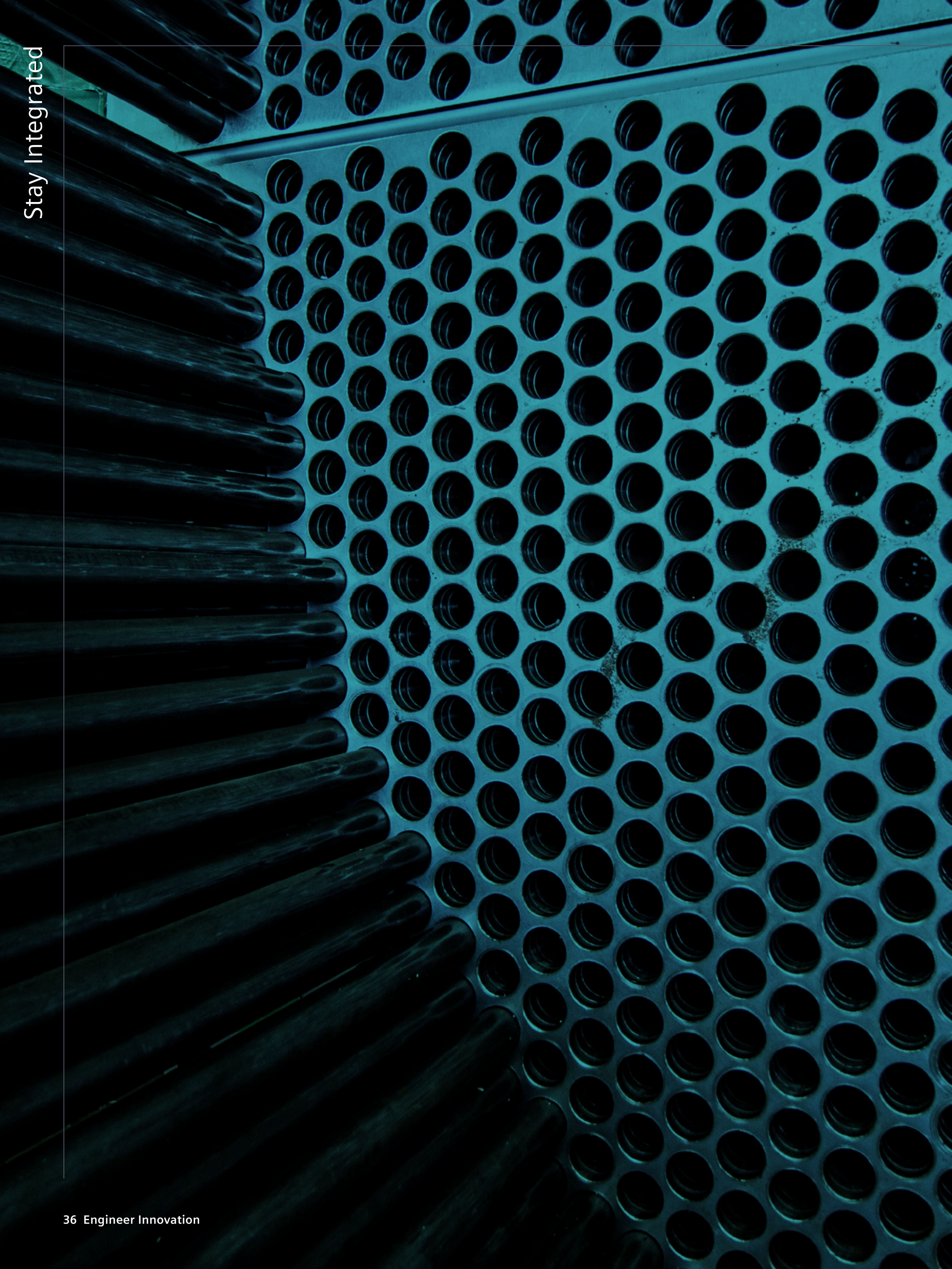
RDX will shortly be announcing a demonstration flight using the same rocket engine that will be used to put satellites into orbit. They are then aiming a first orbital commercial launch within the next two years. To find out more, head to https://www.reactiondynamics.space/. ■



First Left:
Reaction Dynamics' engine test cell

First right:
Bachar Elzein, Reaction Dynamics Founder

Second right:
First iteration of the orbital engine tested in early 2021



The role of the digital twin in energy operations

Achieve operational excellence in the energy sector

By Joelle Beuzit

The digital twin: industry buzzword or valuable technological advance? While many industries acknowledge the value of the technology and gradually adopt it, the energy and utility industry has yet to reach digital maturity. Digital technologies permeate the sector more slowly than they do other industries. The digital twin is no exception: in 2020, less than 40% of oil and gas companies had implemented or planned to implement the technology.

On the other hand, the energy sector is under tremendous pressure to achieve superior efficiency across all its operations. Operational efficiency is a key driver for the adoption of digital technologies.

So, what roles can the digital twin play for the industry and what benefits does it bring?

The digital twin lifecycle

To start with, a short recap: the digital twin is a virtual replica of a physical object, system, product, or facility, depending on the scale of the investigation. The digital twin is not a digital snapshot of a product at a certain point of its lifecycle. It follows the product lifecycle and lives across it, from the early days of conceptual design to manufacturing, operational use, and retirement.

In the capital-intensive energy sector, equipment and facilities remain active for 20 to 30 years or more. Preserving and extending the lifetime of expensive machinery and amenities translates to massive savings, while planned or unplanned downtimes may cost millions of dollars.

Particularly in this sector, the digital twin helps better analyze, understand, and eventually predict operational issues. It offers a critical advantage while possibly saving operational expenses. A predictive digital twin can help achieve operational excellence. Today, real-life examples reveal the value of the digital twin in the energy sector and demonstrate the role of predictive engineering analytics in enhancing efficiency.

Predictive data analytics for the digital twin

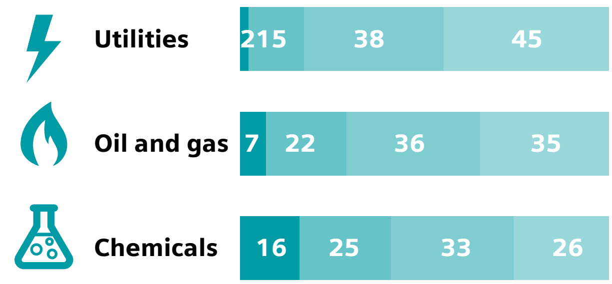
What is the traditional process for ensuring a product or system's operational efficiency? It is a functional loop that starts with

EXHIBIT 2
Digital Operations maturity

Four levels of digital maturity

Digital Champion	The company has a clear position in the marketplace with complex and tailored internal, partner and customer solutions offered via multilevel digital interaction
Digital Innovator	The company has digitized most internal operations and has taken steps to connect with external partners/customers to exchange information and collaborate
Digital Follower	The company has integrated internal functions such as sales, manufacturing, sourcing and engineering, enabling them to collaborate more closely
Digital Novice	The company has some isolated digital solutions and applications, but these exist at the functional or departmental level within the organisation

Level of digital operations maturity



Source: 2020 Digital Operations survey, Strategy& analysis

retrieving operational data from the sensors instrumented on the system. This data is captured and curated in one location. Using a dedicated software tool, the engineers perform data analytics and translate the retrieved information into actions: they now have sufficient evidence to make an informed decision. They can control, maintain or improve the system in operation.

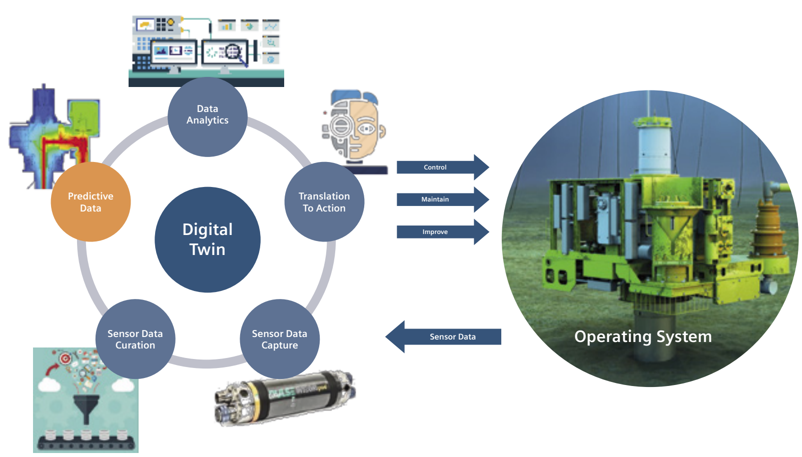
Now, what if the system is so remote or intricate that it's nearly impossible to retrieve operational data? What if the engineers need to assess the impact of future or unexpected events on safety and integrity? What if they're trying to push the system beyond its current boundaries, under extreme environmental conditions, or beyond its expected lifetime? To answer these questions, engineers need more than measured data from sensors. They need predictive data. Predictive data combines the facts nested in the data with simulation to turn information into insights. It becomes available in places and times where measurements are impossible.

The digital twin is not about simulation alone. It relies on predictive engineering analytics, the application of multidisciplinary engineering simulation, coupled with intelligent reporting and data analytics.

Ensure the integrity of a heat exchanger
Now, here comes the real-life example. Let us look at how the digital twin can support the operational integrity management of a heat exchanger. A heat exchanger is a system that transfers heat between two or more fluids. Heat exchangers are standard in many facilities and offer heating, refrigeration, air conditioning, cooling of power stations. They are part of many chemical and petrochemical plants, petroleum refineries, natural gas processing facilities, and water treatment systems. The systems typically consist of a tube bank and a plate; the steam goes into the bank of tubes and comes out again on the other side.

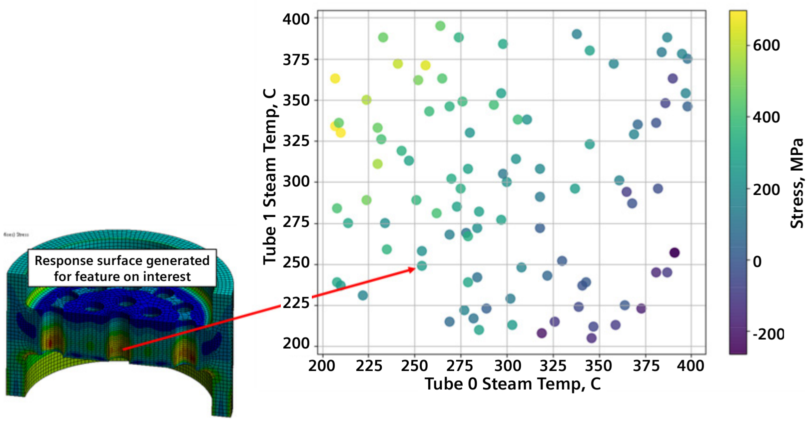
In this case, the heat exchanger displays a poor flow distribution into the tube bank. It generates high-temperature gradients with hot and cool spots. As a consequence, it induces thermal stresses, fatigue issues, and potentially cracking of the pipes. And therefore, it causes a potential integrity challenge.

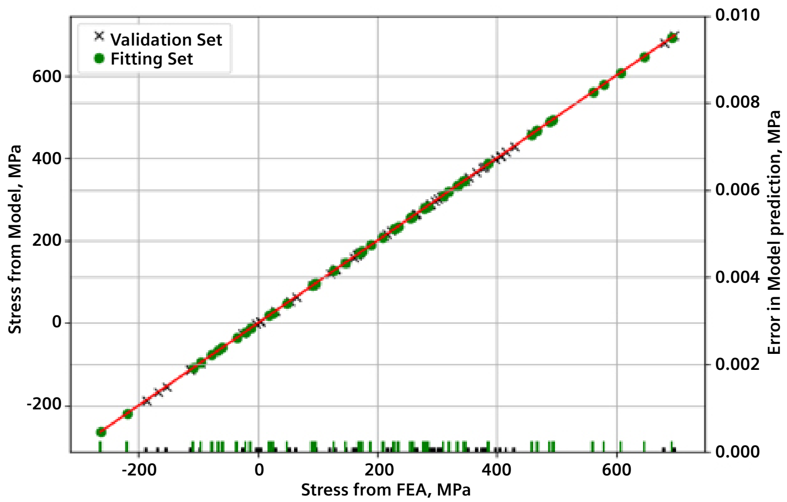
Digital twin for operations – the full loop



First left:
The four levels of digital maturity of the energy and utility industry (Source: Strategy&)

Second left: The digital twin in operations





First right:
The correlation of the temperature and stress data at key locations of the steam tubes.

Second right:
The correlation between the reduced-order model and the detailed stress predictions for one of the components in the heat exchanger

How can the digital twin help address this challenge? Measuring the temperatures is the first step, but it won't yield insights into the system's future behavior. Accurately assessing and even forecasting the system's integrity would require additional information such as the stress history and the realistic remaining lifetime of the equipment. In short, it requires more insights from the temperature data. How do we retrieve these insights? There is no single method to undertake predictive engineering analytics. Modeling and simulation can take several forms, from the extensive 3D computational fluid dynamics and finite element analysis models to system simulation models or reduced-order models. Selecting the most appropriate technique depends on the simulation objective, the required details, and the acceptable time in which results are required.

To assess the heat exchanger's integrity, we can generate a model that comprises both high-fidelity finite element analysis and computational fluid dynamics. The model will help us understand and predict every detail of the flow distribution and heat transfer. But simulating these phenomena is a time-consuming activity. Additionally, it may be complex to integrate the operating history and the working life of the equipment. Is the high-fidelity approach too time-consuming? Can we combine it with reduced-order models and teach the reduced-order models how to generate data in real-time?

Define a process to predict integrity.
The digital twin process starts with the same steps as the functional assessment loop. Sensors will measure the temperatures from the tube bank. The next step is to use a fluid dynamics simulation to understand the flow distribution in the tubes. Then, the engineers model the stress distribution within each tube where the heat transfer properties are known. They correlate it to the stress data using the finite element analysis model. In that way, they identify locations in the system which are critical to the system's performance. By characterizing the phenomenon across a set of scenarios, we can correlate the stress at different locations and the critical locations of the system with the temperatures we can measure. The final step is to generate a reduced-order model that engineers train to match the detailed predictive data.

The chart below (Figure 4) shows the correlation between the reduced-order model and the detailed stress predictions for one of the components in the heat exchanger. This correlation is beneficial to understand the effect of temperature-induced fatigue. Most importantly, the correlation is the starting point to build a reduced-order model that delivers a real-time assessment of stress and fatigue.

Application of the reduced-order model
Now that the reduced-order model is fully functional, it drastically speeds up and enhances the operational assessment process. Again, it all starts with measuring the temperature inside the tubes. The measurement results in a time-series data stream from the tube bank. Inserting this data into the reduced-order model will automatically reveal the stress response. The reduced-order model-based fatigue analysis renders an updated fatigue life assessment. Based on this assessment, the engineers can inform operations: plan repairs, maintenance and downtimes, judge if

lifetime extensions are appropriate. They have the operational temperature data at hand to create a real-life, real-time summary of the system's structural integrity. Predictive data helps them make informed decisions.

Data is essential

The digital twin is a lifecycle notion. As engineers, we generate a tremendous amount of data in every step of the engineering process, from the initial concept through detailed design to the manufacturing and the operational life. This data should not be short-lived information. A meaningful usage of it will yield tremendous insights into the performance behavior of systems. It is essential that if we generate the data, we use it in operation.

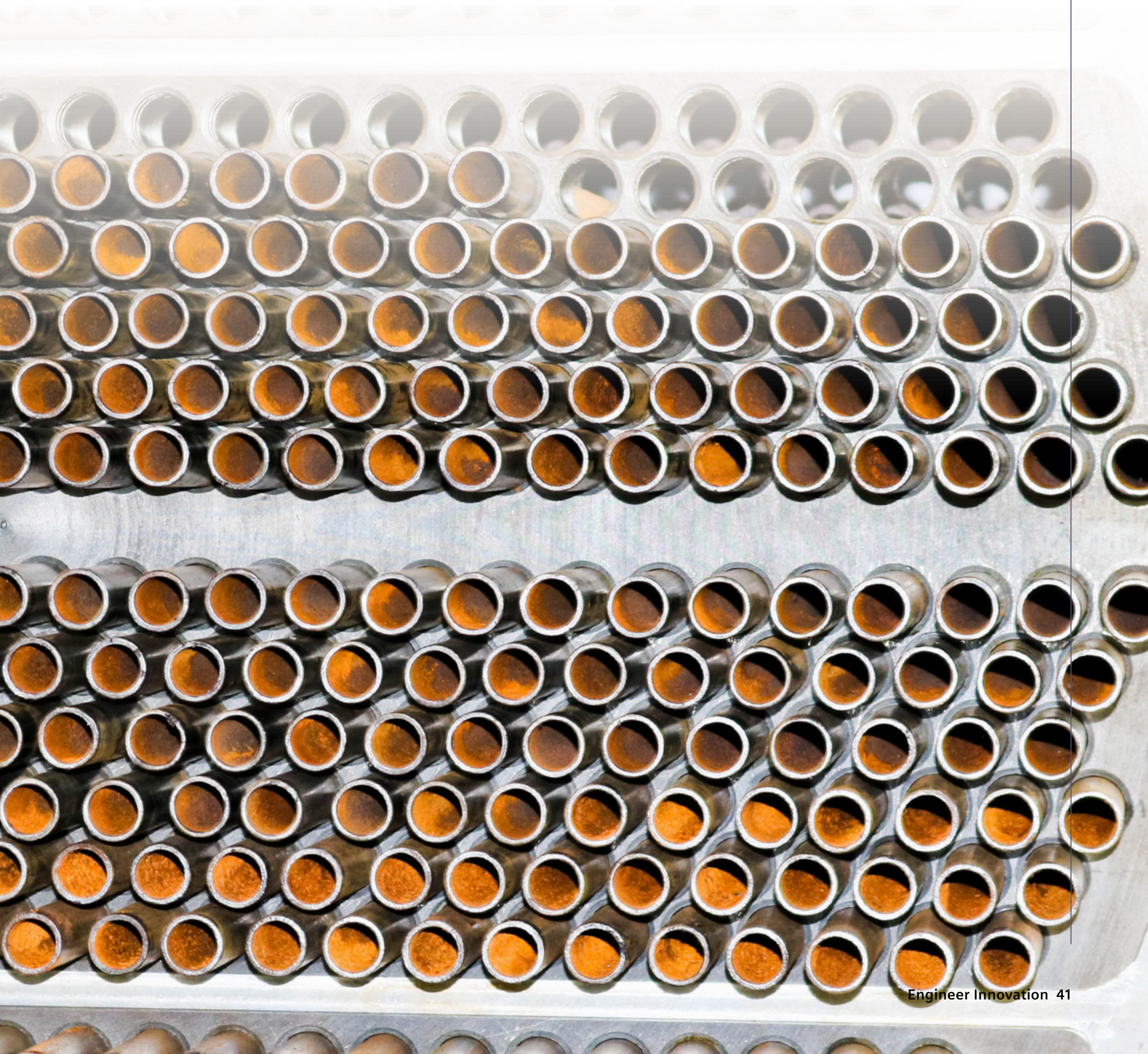
For the energy and utility industry, it implies a change in how the supply chain works together. Operators take the equipment and put it through 25 years' worth of operation. In the near future, they'll have to work hand-in-hand with the equipment providers, who have the detailed technical and design knowledge of the products, and with the technology developers, who have the tools to create digital twins and the know-how to embed those into an operation. The digital transformation of the industry commands a

closer collaboration of all involved throughout the engineering life cycle.

Which simulation method should you use in the predictive element of your digital twin? No technology prevails. Different simulation types play different roles in supporting concept, design, manufacturing, and operations, from high-fidelity models to system simulation and down to a reduced-order model. It depends on where you are in the lifecycle and what data you need. Predictive engineering analytics provides insights. In operations, it reveals its true value when coupled with field data. The example above highlights the immediate benefits of relying on a digital twin of a heat exchanger. But possibilities are endless, and applications of the technology range from integrity management to production performance and safety management. ■

Explore the breadth of the Simcenter portfolio for the oil and gas industry on the Siemens website.

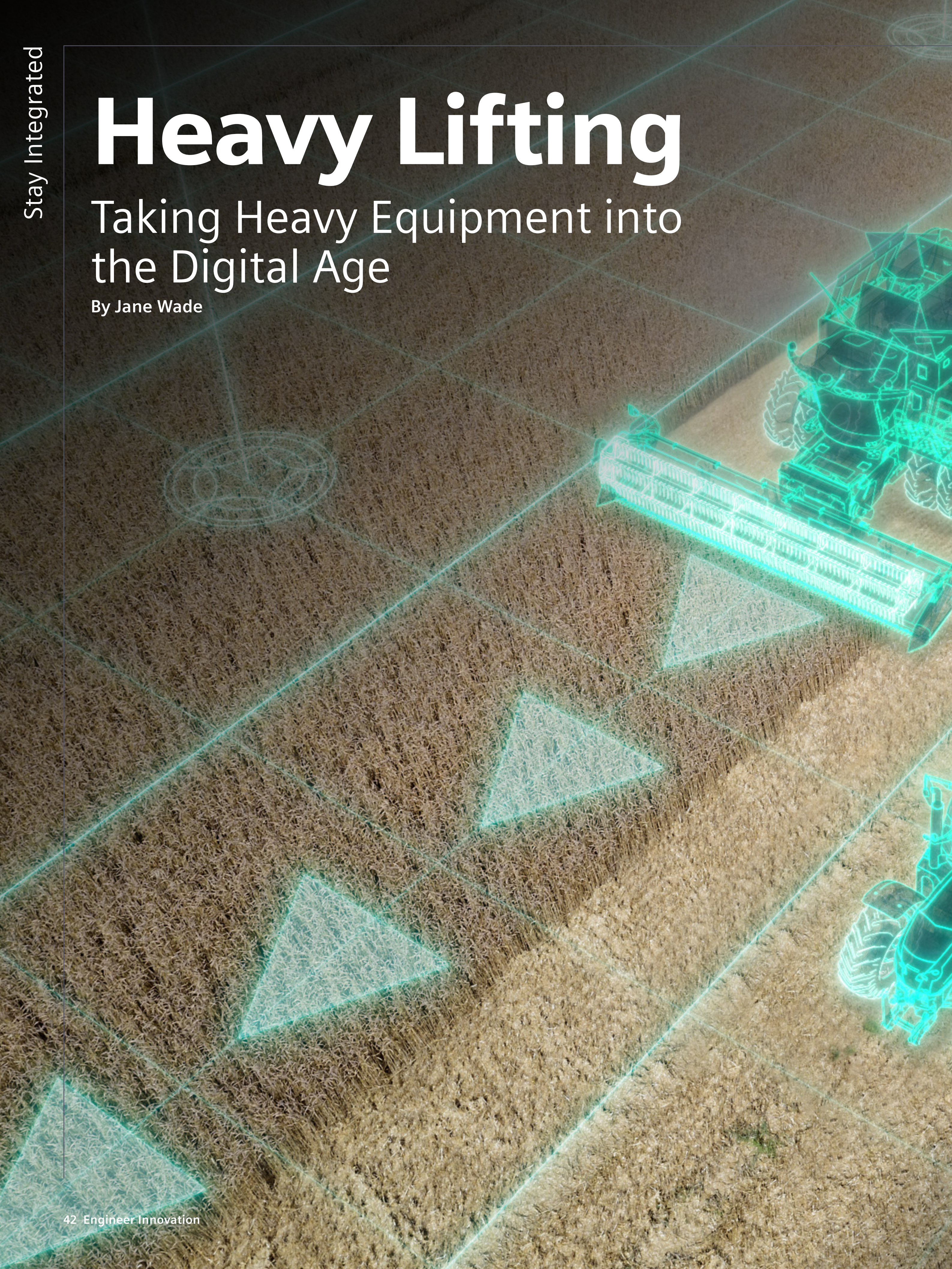
Special thanks to Matt Straw (Norton Straw), Rikesh Mistry (Norton Straw), Ravi Aglave, Doug Kolak & Maged Ismail (Siemens Digital Industries Software)

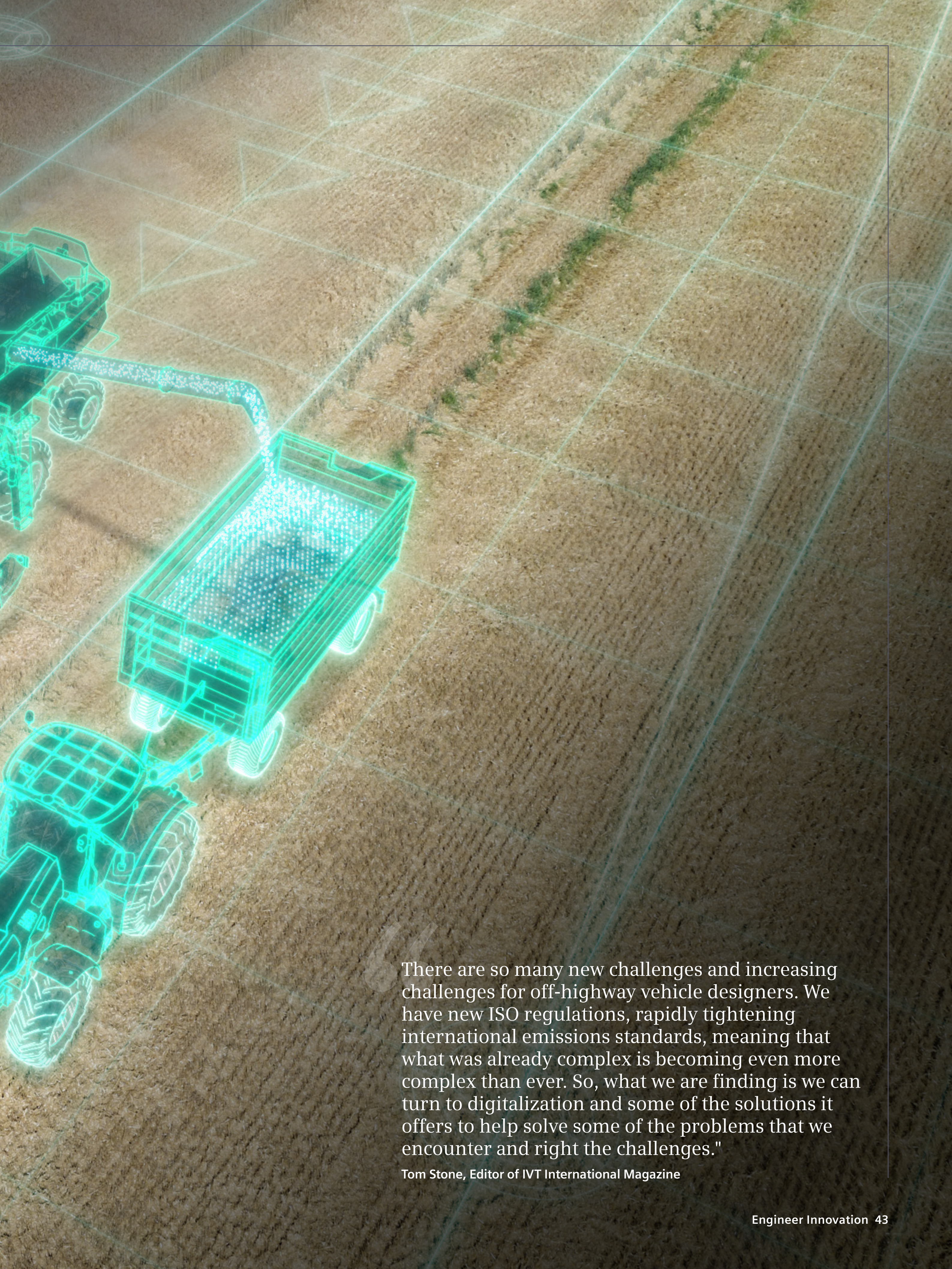


Heavy Lifting

Taking Heavy Equipment into the Digital Age

By Jane Wade





"There are so many new challenges and increasing challenges for off-highway vehicle designers. We have new ISO regulations, rapidly tightening international emissions standards, meaning that what was already complex is becoming even more complex than ever. So, what we are finding is we can turn to digitalization and some of the solutions it offers to help solve some of the problems that we encounter and right the challenges."

Tom Stone, Editor of IVT International Magazine

None of the following statements will come as a surprise for our readers: Worldwide, in some regions rapid, population growth is putting increasing demands on our infrastructure, the infrastructure that delivers our food, transport and power in particular.

The heavy equipment industry faces stringent regulations, that differ country to country, but are primarily concerned with operator safety and minimising environmental impact of activities.

Ever greater exploration of variable environments as we seek to gather more resources, feed, shelter and nurture a growing population globally.

Individually each of these challenges may seem like an insurmountable ask, but collectively they put the industry under tremendous pressure. Does increased digitization and deploying the digital twin offer some solutions?

Recently a group of industry experts from across the Heavy Industry supply chain gathered to talk about the challenges they faced and what role digitization played in their teams' activities and methodologies. Gennaro Monacelli, head of design analysis and simulation at CNH (Case New Holland) Industrial; Yohann Brunel, upstream transmission manager, Poclain Hydraulics; Alastair Hayfield, senior researcher Interact Analysis and Gaetan Bouzard, industry manager, Siemens Digital Industries Software. Against a backdrop of increasing challenges for off-highway vehicle supply chain, new regulations such as ISO (International Standards Organization) regulations and rapidly tightening international emissions standards particularly Stage V for NRRM, increased electrification and lower total cost of ownership how do these businesses approach the future?

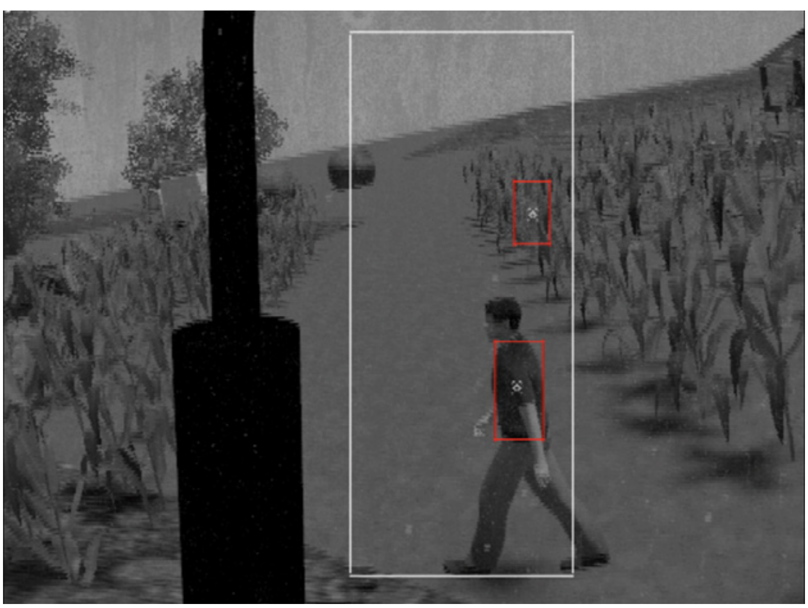
Whilst the three challenges are without doubt connected, in this article we try to approach each one to understand the unique drivers and nuanced solutions.

> "You are bringing in a lot of new engineering requirements and I think a company like Siemens that has those simulation tools and can help partner with companies. They will find their services are in strong demand now because OEM's need that support to help them make that transition."
>
> Alastair Hayfield

Worldwide population growth
The worldwide population is growing by 1% each year, this puts increasing demands on available land for farming, for building and for the infrastructure such as water and power supplies in addition to the natural materials required to make this possible.

Farming needs to increase productivity to ensure a sustainable food supply, increased urbanization puts demands on the construction and mining industries. The productivity growth required of these industries faces the double threat of a lack of skilled labor, and that available may be either aging or not located at point of need.

Targets
To meet demand, agriculture in 2050 will need to produce almost 50 percent more food, feed and biofuel than it did in 2012. This FAO estimate takes into account recent United Nations (UN) projections indicating that the world's population would reach 9.73 billion in 2050.



Innovation in Heavy Equipment to tackle the challenges because of population growth needs to focus particularly on productivity, also considering the total cost of ownership. It also needs to be smarter, providing solutions to optimize ground exploitation.

More stringent regulations
Operator safety is paramount along with ensuring sustainable practices to support the local and global environment. Heavy Equipment has lagged other areas as it moves to electrification, but the market needs to deliver machines compliant with emissions regulations. Alternative power sources along with all round improved machine operability (considering decreasing skills in workforce) are also key drivers contributing to the increased sustainability required to obtain compliance with stage V emissions regulations.

Operator comfort is also an essential consideration for future machines, often operating in harsh, rugged environments for extended periods, operators should not be subjected to sustained noise of vibration.

Exploration of variable environments
Whilst not entirely new since field conditions have always posed challenges for heavy equipment manufacturers, as ground exploitation is pushed to its limit the variability of such environments also increases. Machines needs to be incredibly versatile, operating under large temperature and humidity variations, often in muddy or dusty environments.

OEMs need to ensure operability and reliability wherever the machine operates, not just on homogenous machines but also on customized machines optimized for a particular use case or operator requirements.

Against this backdrop how do our expert panel ensure their product delivers, wherever they fit in the supply chain?
The time-to-market for manufacturers remains short but the demand for reliability and robustness has increased, Gennaro Monacelli, CNH Industrial, has seen a shift in the mindset of its engineering in response to this:

'If you want to find a solution you go in the field and test. This is no longer acceptable in terms of delivery times. Our industry has a big challenge in front of us.'

Instead, CNH Industrial look to product engineering to do as much virtual testing early in the product development, so when the design phase is released most of the issues have already been checked. Product engineering on this scale is only possible with robust simulation and test operations. It has been a huge shift in philosophy, meaning that when a physical prototype is built efficiency and reliability are already achieved. Not only does this help get a better product to market quicker but less physical prototypes also means a more environmentally aware approach.

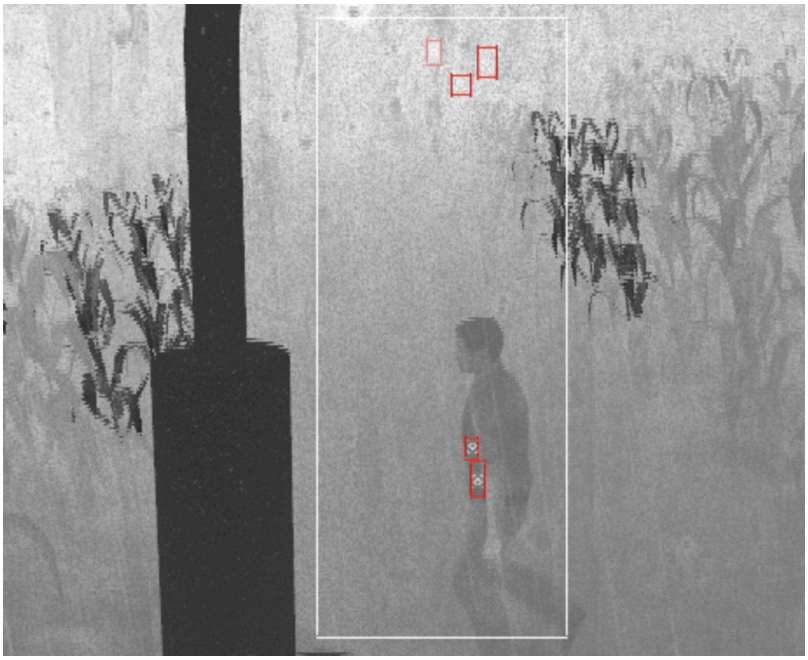
Poclain see the benefits of this approach, 'the capability to have a better insight into the products, to improve our learning curve when we have specific dynamics of a specific problem and to better master the performance of a product.' That is the power offered by simulation early in the design cycle.

The skilled labor shortage is not confined to the field, as they break new ground, Yohann Brunel, Upstream Transmission Manager, Poclain Hydraulics:

'The electrification of autonomous vehicles is already challenging everybody. We have innovative technologies to integrate, so we see that utilization and simulation can help us accelerate the learning curve. We are adopting increasingly a system approach, and to be able to spread even more simulation to more people who are non-specialists, we need these kinds of tools.'

The advice from this panel suggests frontloading simulation and virtual testing helps to model many of the engineering complexity early, ensuring few surprizes at the later stages. Using tools that bring powerful physics into the hands of non-specialists at the CAD (Computer Aided Design) stages breaks down some of the silos and enables a more seamless information transition.

Breaking those silos is essential for complex equipment design, by shifting left and improving data and model sharing using tools designed with the user experience paramount. **These tools allow non-exploratory experts from the domain to tap into the capabilities of the digital twin.** Consider the complexity of electrification, everything is interconnected; the cooling loop, the battery, and the cabin



comfort for the operator, the demands are all interdependent and connected. Considering each system in isolation simply will not work.

CNH Industrial have developed this inclusivity even further with immersive technology, in the virtual reality realm. This has enabled them to involve even more knowledge and opinion at the design stage, machine operators and dealers can virtually test the cab before any prototypes are built. It led to some unexpected outcome... including repositioning the water bottle holder.

Achieving a seamless workflow between the engineering disciplines is quite a challenging, as Yohann explains:

"Yes, this is a challenge. The main tool that we use to gather different physics together, different domains, is 1D simulation. We use system simulation to do that. It enables us to cover different physics. It is enabled us to cover different level of details and then the program is to ensure the numerical continuity between models of each component, simplify the model that we need at system level. For the component level we need fine sense to have connection between the design parameters and the characteristics we need a more physics-based model. A system model we are more interested in the characteristic itself, so we can have a model based on data or something. We must ensure that we have continuity between them to be sure there is

no disconnect between the model of the component and the model of the system. This is really a big challenge for us."

How do the experts see the role of testing in the development of Heavy Equipment?
This area threw up two interesting answers, the expected answer was that we do less tests and whilst overall that was the case it was more nuanced.

Poclain changed the way they use tests, they build in elementary tests on components to test the parts they have, confirming or defining the important parameters for the area to be considered. 'We only do necessary tests to validate it and as soon as we have confidence in the model we can iterate and avoid test and fail with real tests on real prototypes.'

CNH has also used simulation to build smarter tests, having started at 5% virtual testing they have now reached 55%, with a target of 80% in five years. A key area for CNH is occupant safety and rollover tests of cabs are essential but also expensive, time-consuming, and potentially wasteful with cabs being destroyed in the process.

'We were about 85% the correlation, but we discovered that correlating exactly, not only simulating, not only the cab, but also the station, the testing ship station and moreover materials, we reached the 95% correlation. This is the target that is important for us, so we do not need to destroy a cab. When we go to the final testing lab, we can just have one shot and do not have any further cycles.'

Smarter testing with simulation has resulted in more effective and quality data acquisition testing, and less destructive testing with the associated environmental and cost benefits.

Drowning in data
Doing more simulation, more virtual testing, more immersive testing, and more physical testing results in more data. Data is also acquired from the field in live operations from sensors on the equipment. The volume of data can be vast, more is not always better.

CNH are seeking better ways to use this data, to join up a seamless workflow that makes use of available data throughout but does not needlessly collect it.

There is one area where the data from virtual testing has proved invaluable not only in reducing costs but also time to market, homologation and ensuring the many machine variants all meet the required standards and certification. CNH has a close eye on their CO_2 emissions from these tests, ‘When we build a prototype, we produce a lot of CO_2 emission and then we destroy it. WE are analyzing this to not only save money but also emissions.’

Alistair Hayfield has seen the data challenge with many clients, ‘it’s actually pretty costly and difficult to store, warehouse and transmit all of the found data. OEMs need an approach where they are selecting the best or most relevant data to work against you own model.’ But used well that data offers many opportunities particularly for automation. Using the data in automation can be key to bringing the machines to market faster, and in a cost-effective way.

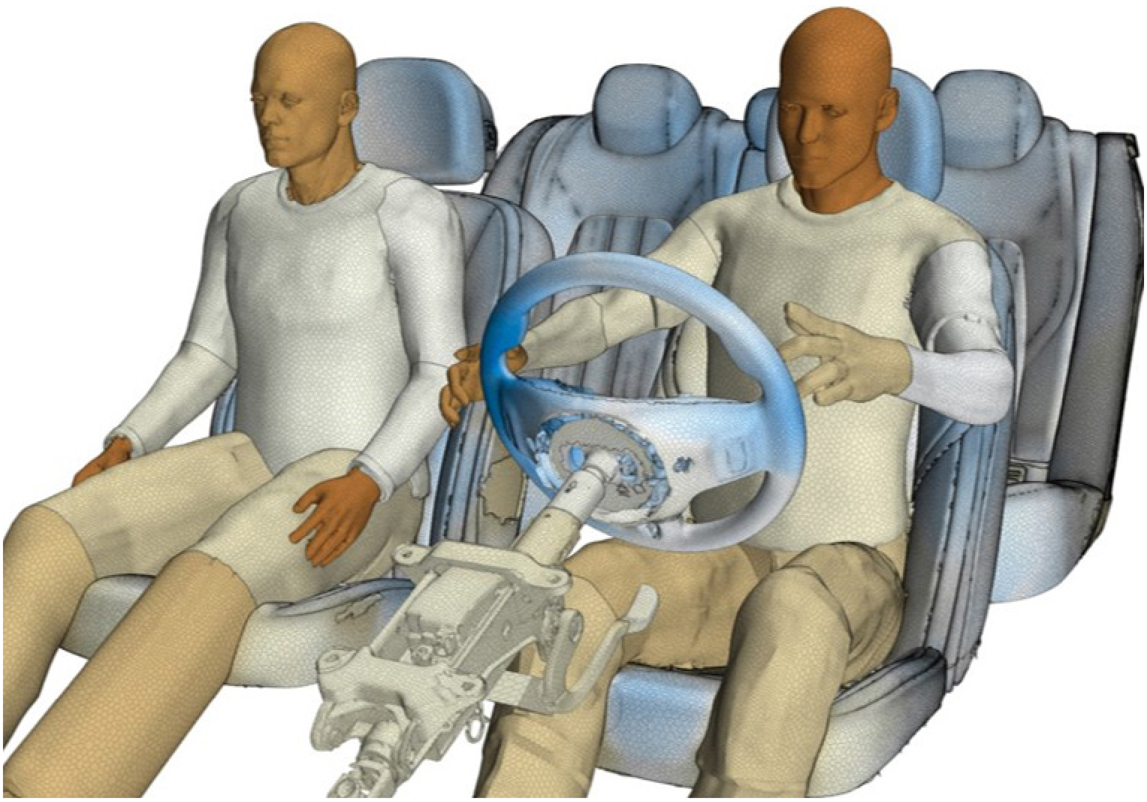
Does increased digitization and deploying the digital twin offer some solutions?
The heavy equipment industry is now firmly on the digitization journey, using simulation earlier in design, a greater use of virtual testing and immersive technology along with using more data to gain insight for future improvement.

And whilst all the experts agreed they have not yet reached the destination of the full ‘digital twin’ they are all benefitting from the increased digitization they can realize from using simulation and test. They are adopting a hybrid approach, shifting from real tests, real prototypes, real field-testing to increasing the role of virtual and immersive. This is a journey that has only just begun but is already taking on those huge challenges that the industry needs to overcome to deliver the world we will be enjoying tomorrow. ■

If I don't use AI, am I really an engineer?

Busting the myths of artificial intelligence and machine learning in engineering.

By Christina Kothlow, and Krishna Veeraraghavan

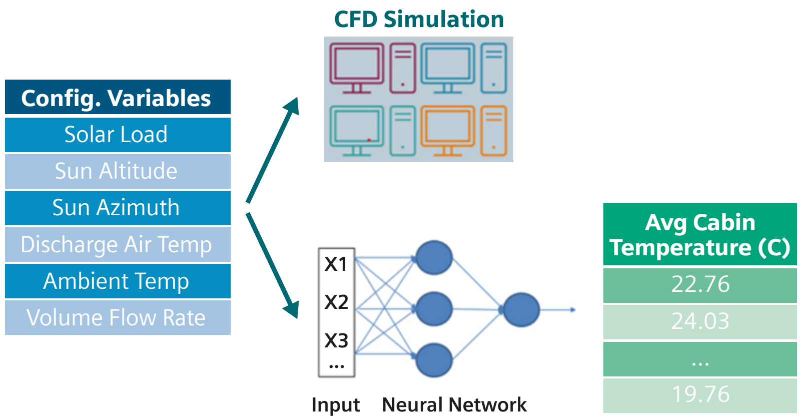


As Artificial Intelligence (AI) has become more ubiquitous in our everyday lives, so too has they hype. There are some pretty scary premonitions about AI too, largely thanks to the science-fiction and dystopian literary genre, but even some of the leading lights in science and technology have some strong opinions.

What is AI?
AI is a multidisciplinary topic that enables machines, devices, and computers to think and make decisions in a way that would seem intelligent. AI helps machines and programs make smarter decisions by learning and improving in an iterative process based on the information they collect.

In the future, AI in engineering may focus more on collective intelligence. Engineers and computers working together in feedback loops to identify problems and develop solutions that can make the design process and systems work more efficiently. This would enhance the capabilities and contributions of engineers. This sounds positive, a worthwhile contribution to humanity and real people still central.

Collective intelligence
Collective intelligence somehow seems more sinister, it refers to ways that data and technologies bring people, machines, and computers together to achieve outcomes that were previously beyond our expectations. Psychologists define collective



> "The development of full artificial intelligence could spell the end of the human race."
>
> Stephen Hawking (2014)

intelligence as groups whose general ability is to perform well not on a single task, but on a wide range of different tasks. This is possible to achieve by combining human intelligence and machine learning, the ultimate 2+2=5?

Machine learning

Machine Learning (ML) takes us even further into science-fiction territory, a subset of AI, a self-adaptive algorithm that uses statistical algorithms to build and train systems and models. These systems and models can learn and improve without being explicitly programmed to do so and then make predictions or identify hidden patterns in the data. Two types of machine learning widely used are supervised and unsupervised learning. All supervised learning will fall under either regression or classification problem. Input data for both cases can be numerical and categorical.

Deep learning

Deep learning moves us from science-fiction to potential dystopia but is simply a further subset of machine learning. Some of the most frequently used deep learning networks include convolutional neural networks, auto-encoders, transformers, and generative adversarial networks (GAN). Deep learning utilizes hierarchically organized artificial neurons to process data for extracting higher-level features from the raw input and for achieving machine learning objectives. Deep learning is distinguished by its use of many layers of artificial neurons and, consequently, many parameters and hyperparameters. Optimizing hyperparameters can have an impact on the training of machine learning algorithms (a few examples include number of clusters in clustering algorithms, Bayesian optimization, gradient-based optimization, etc.).

Having established some common definitions, we can do some myth busting.

Myth #1: Numerical models are the only solutions available to solve difficult engineering problems. AI is not accurate enough to be a good fit for Computational Fluid Dynamics (CFD) and engineering problems

Reality: Thanks to technological advances, AI/ML solutions now exist that work well on sub-systems with very minimal prediction error. Simcenter Engineering & Consulting Services have worked with customers to use AI/ML in design predictions to minimize CFD simulations with great success and good accuracy.

Myth #2: Data science is easy and there are open-source tools that can be used

Reality: Generic machine learning algorithms cannot handle customer-specific engineering problems. Different applications require different machine learning algorithms and further problem-specific refinement (for example shape detection techniques). Although there are widely available image recognition algorithms, companies must develop an in-house shape detection algorithm to detect various shapes or components of a vehicle.

Myth #3: AI doesn't require people to run it

Reality: The value of AI lies in its ability to augment the capabilities of computer engineers and domain experts. By performing the monotonous and repetitive tasks, it helps engineers focus on solving more complex problems using CFD tools, such as Simcenter, to generate more meaningful simulation data for future predictions. AI is the helping hand, not the hand itself.

Myth #4: The more data, the better

Reality: AI in CFD needs smart engineering data, such as Key Performance Indicators (KPI), relevant to the problem, to be successful. Simcenter Engineering Services uses feature engineering technologies to achieve data reduction from simulation data to enable AI to deliver high-quality solutions. As with many things more data isn't always better, but relevant data that gives insight is.

AI – more fact than fiction

AI has transformed technologies in every industry. Applying AI to CFD applications can be a strategic asset to companies since it helps to reduce costs and create new differentiated values. AI-driven smart solutions offer substantial benefits to CFD engineers, designers, and analysts:

- Reduce computational, design program, and operational costs by creating more designs per simulation at a faster turnaround time
- Reduce the process and program development turnaround time with ML based surrogate models and smart AI driven workflows to expedite turnaround time
- Enhance the accuracy of simulations by flagging anomalies and providing knowledgebase workflow assistance in the CFD process. This includes CAD, physics modeling, mesh settings, and postprocessing
- Improve product performance and efficiency by creating an ecosystem to simulate, predict, and optimize the product in a seamless way
- Provide knowledgebase workflow assistance in CFD

If AI offers so many advantages for CFD, why aren't all engineers doing it?
Implementing AI, particularly for a niche technology like CFD, can present some operational challenges.

Database management: building and maintaining simulation and design database is a monotonous and expensive process which involves alignment with IT and the various engineering groups. Engineering groups themselves are often disconnected, so the required coordination with an additional department can be a hindrance.

Extracting and then training the data for AI in CFD, there is a lack of required data science skills to extract desired features, build and train the data set for integrating ML techniques with CFD, CAE simulations and for design predictions.

Talent, delivering AI capabilities in CFD designs and simulations requires talent in machine learning, deep learning techniques and CFD skills, and these skills are still largely developmental across the engineering workforce.

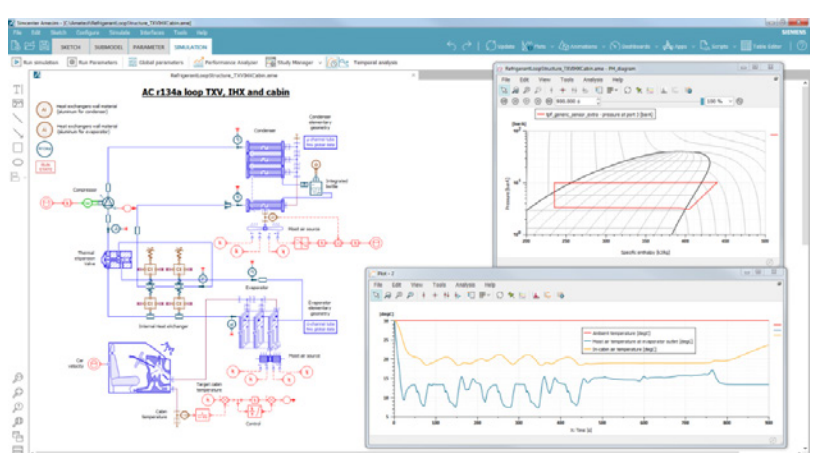
What's the solution?
The Simcenter Engineering Services group at Siemens has developed AI solutions for CFD to solve these and other AI-related problems

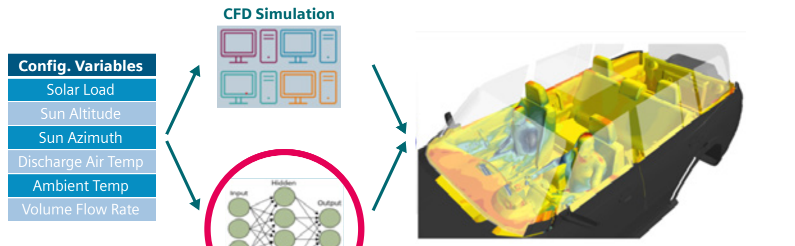
> "Nobody phrases it this way, but I think that artificial intelligence is almost a humanities discipline. It's really an attempt to understand human intelligence and human cognition."
>
> Sebastian Thrun (2013)

companies face. These solutions enable companies to:

- Connect CFD with AI and multi field science to assist engineers in multi-physics design exploration studies and AI-enabled control actions to enhance product performance
- Drive innovation in designs and simulations by enhancing their digital twin capabilities, by developing and deploying customizable AI solutions
- Realize successful transformation for AI in designs and simulations by providing domain knowledge, build and train ML models with CFD and multi-science data and provide access to deep learning and ML techniques

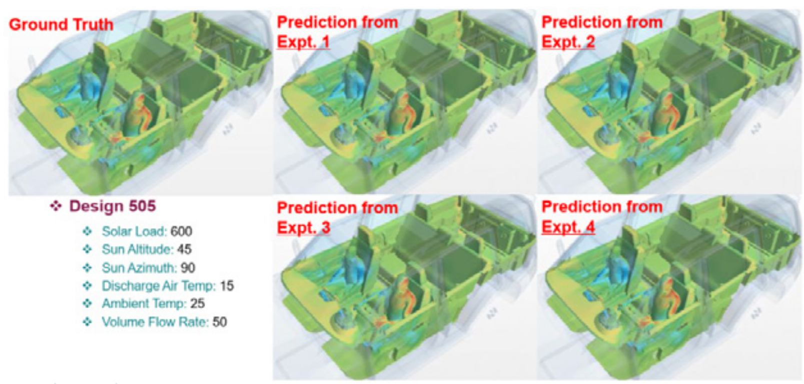
Going beyond CFD
Industrial solutions for AI in simulations have been developed with the Siemens groups including model-based systems engineering, predictive analytics, physical testing, and





	Training Dataset	Training Time	Prediction Error
E#1	500 CFD Sim.	3.08 hrs.	$1.1232*10^{-4}$
E#2	1000 CFD Sim.	4.25 hrs.	$6.3939*10^{-5}$
E#3	1500 CFD Sim.	5.40 hrs.	$4.9629*10^{-5}$
E#4	2000 CFD Sim.	6.46 hrs.	$4.8784*10^{-5}$

Source: Siemens Predictive Analytics Group



> "Artificial intelligence would be the ultimate version of Google. The ultimate search engine that would understand everything on the web."
>
> Larry Page (2000)

system simulation engineering. These synergies allow the Simcenter Engineering Services team to leverage domain expertise and deliver value that goes beyond CFD by focusing on AI/ML and statistical techniques that address customers goals.

If this all sounds theoretical and futuristic, then keep reading.

Real-world applications for AI in CFD

Predict discrete temperature using ML

For engineers responsible for thermal management, regression techniques can be used to develop a prediction algorithm based on input data (such as numerical/categorical) and output data (numerical).

In the above example, the team trained a neural network to predict the average temperature of a vehicle. Completed using 500 random samples from 600 data samples generated by Simcenter for various combinations of operating conditions. The KPI (temperature) was extracted to train the model. Of the 600 samples, the team used 500 for training, and the remaining 100 were used to predict the accuracy of the model. Of 100 data samples, 72 samples had less than 1% prediction error (difference in predicted temperature – actual temperature) and 28 samples had prediction error in the range of 1% to 1.66%. The maximum prediction error in the model was 1.66%, which corresponds to the temperature difference of <5 º C.

Regression techniques can also be integrated with control systems. Using CFD data, engineers can train the regression model, use it to predict values of relevant variables, and then take corrective control actions to achieve the desired target and improve performance (for example, based on the battery range remaining). Additionally, the model can predict the energy load and invoke control actions to adjust the cabin temperature accordingly.

Predict cabin surface temperature using a convolutional neural network

In a similar example, the Predictive Analytics team used data samples to build a convolutional neural network to predict the surface temperature distribution inside a vehicle cabin. In this exercise, a simulation database was generated by running CFD simulations for various operating conditions. While the team tested the application of 500 (Expt.1), 1,000 (Expt.2), 1,500 (Expt.3), and 2,000 (Expt.4) data samples to train the network, the prediction error remained stable. The team tested the accuracy of the neural network prediction with the actual CFD simulation results and found that the results from both techniques matched. We followed the below steps to compute the prediction error:

1. Computed the square error between the true pixel value and the predicted pixel value
2. Normalized it by the true pixel value
3. Computed its average over the entire region.

These tests proved to the team that AI techniques can be used for CFD simulations without compromising accuracy. By applying techniques such as those listed in the examples above, companies can free up their engineers' time and enable them to perform more valuable, complex design and simulation tasks while maintaining accuracy.

Further live examples can be viewed here

Back to the question we posed at the beginning: if I don't use AI, am I really an engineer? The answer today is yes, but in three years maybe not.

Listen to Krishna"s latest podcast:

BLOG ALL ABOUT IT

Can't wait until the next edition of Engineer Innovation to get your fix of the latest Simcenter news? Fear not, we've got you covered – just head over to our blog to find out what's new and what we've been working on.

We're sure you'll find plenty of fun, interesting and informative articles there. And just to prove it, here are a few recent highlights.

Saving lives with CFD
Unfortunately, it looks as though we will be living with COVID-19 for some time. However, we're in a much better position to deal with it now, and that's in no small part down to CFD simulations carried out in both industry and academia across the world.

Earlier this year, Prashanth Shankara wrote about all the ways Simcenter solutions have been used in the fight against the pandemic.

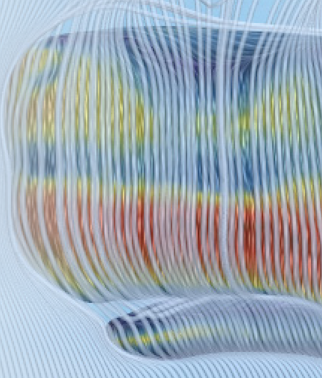
Want to know how safe school classrooms are depending on the level of ventilation? Engineering firm JB&B used Simcenter Flovent to find the answer.

How can we protect bus drivers and passengers from infection? Hearaeus Noblelight used Simcenter STAR CCM+ to help develop a novel ultraviolet-C (UVC) air purifier that eliminates 99.999% of viruses in the air in just a few minutes.

You can also find out how CFD simulations can predict the spread of droplets from a single cough in an aircraft and how the risk of virus transmission can be minimised.

And with many people now returning to the office, you'll be happy to know that Simcenter STAR CCM+ is being used to analyse the risk to individuals and inform how HVAC and indoor ventilation systems can be redesigned to reduce virus transmission.

20 years of Towel Day
This year saw the 20th anniversary of the death of author Douglas Adams. As a big fan of his most famous work, The Hitchhiker's Guide to the Galaxy, Stephen Ferguson decided the best way to celebrate Towel Day was to investigate the aerodynamics of the freefalling sperm whale from the novel.



The whale lived for less than 2 minutes after spontaneously coming into existence several miles above the planet Magrathea, but thanks to the Hitchhikers Guide we know every single thought that crossed the poor creature's mind during its brief existence.

Don't worry too much about how the whale came to be there, instead marvel at how Stephen used Simcenter STAR-CCM+ to calculate exactly how far the whale fell, how fast it was travelling, and how big the resulting impact crater would have been.

Putting the AI into CFD

Ever wondered about the value of Artificial Intelligence(AI) in CFD?

Perhaps you've never considered it. Or maybe you've heard some of the myths which cause people to discount it.

Christina Kothlow and Krishna Veeraraghavan got together to explain just how important AI can be for CFD and dispel the common myths.

They provided a useful summary of AI before going on to illustrate some real-world applications of AI in CFD.

You can read about how the Simcenter Engineering Services team trained a neural network to the predict the average temperature of a vehicle. And how the same team worked with their colleagues in Predictive Analytics to build a convolutional neural network to predict the surface temperature distribution inside a vehicle cabin.

There's also an example of how Simcenter STAR-CCM+ combined with AI helped Subaru drastically reduce the time to identify the link between fluid flow at multiple crank angles to tumble intensity at top dead centre.

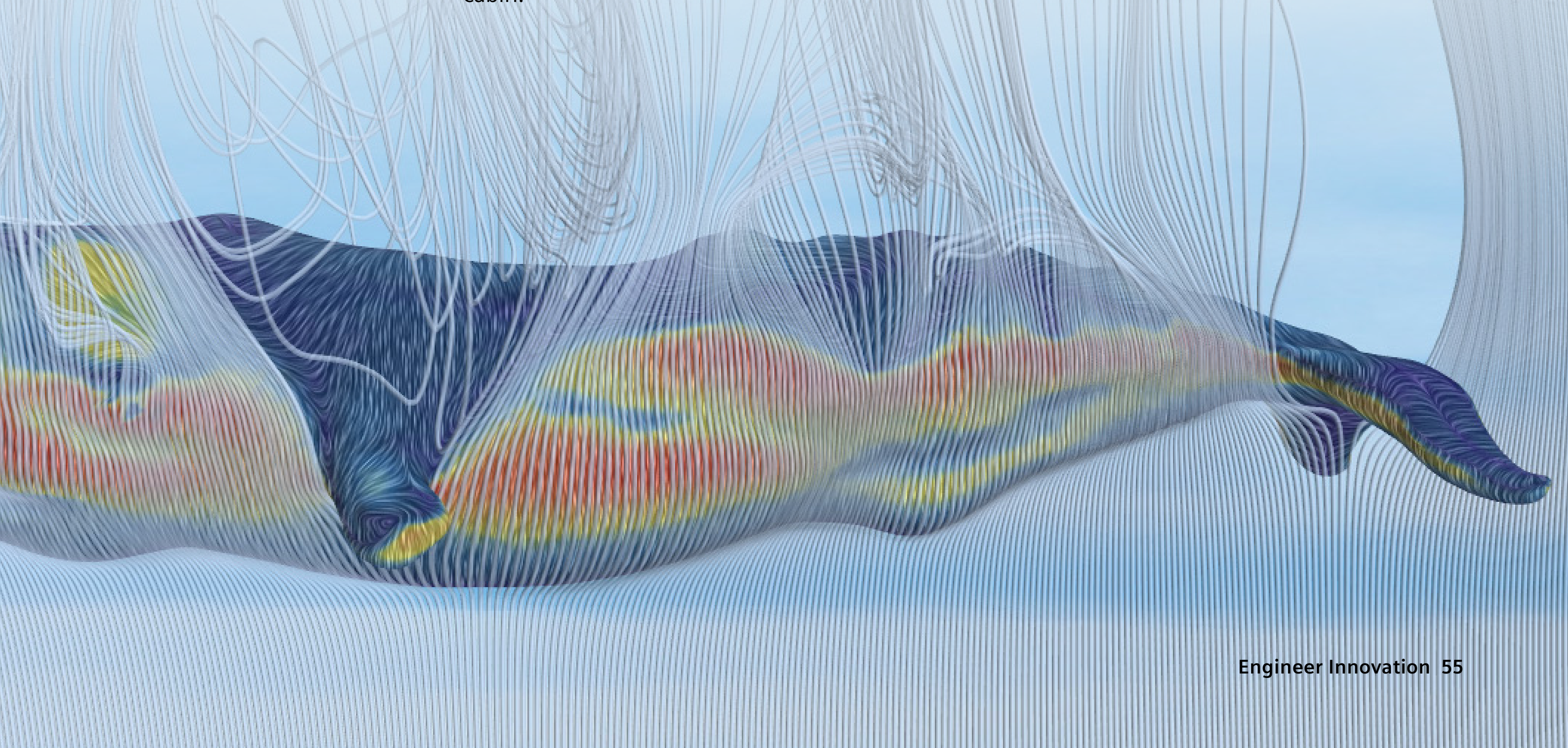
And there's an opportunity for you to get involved by completing a brief survey on the role of AI in CFD.

The sky's the limit

Simcenter is used for so many incredible projects across the world it's impossible to tell you about all of them. But we're always thrilled to see engineers pushing our software to the limit and we've done our best to pick out the top ten best innovations which have been shared publicly.

Lifesaving medical drones, street theatre machines, and flying river taxis are just some of the uses of Simcenter you can read about in Prashanth Shankara's roundup. Or you might be more interested to see how Formula 1 aerodynamics are used in supermarket fridges. It will certainly make you think differently on your weekly shop!

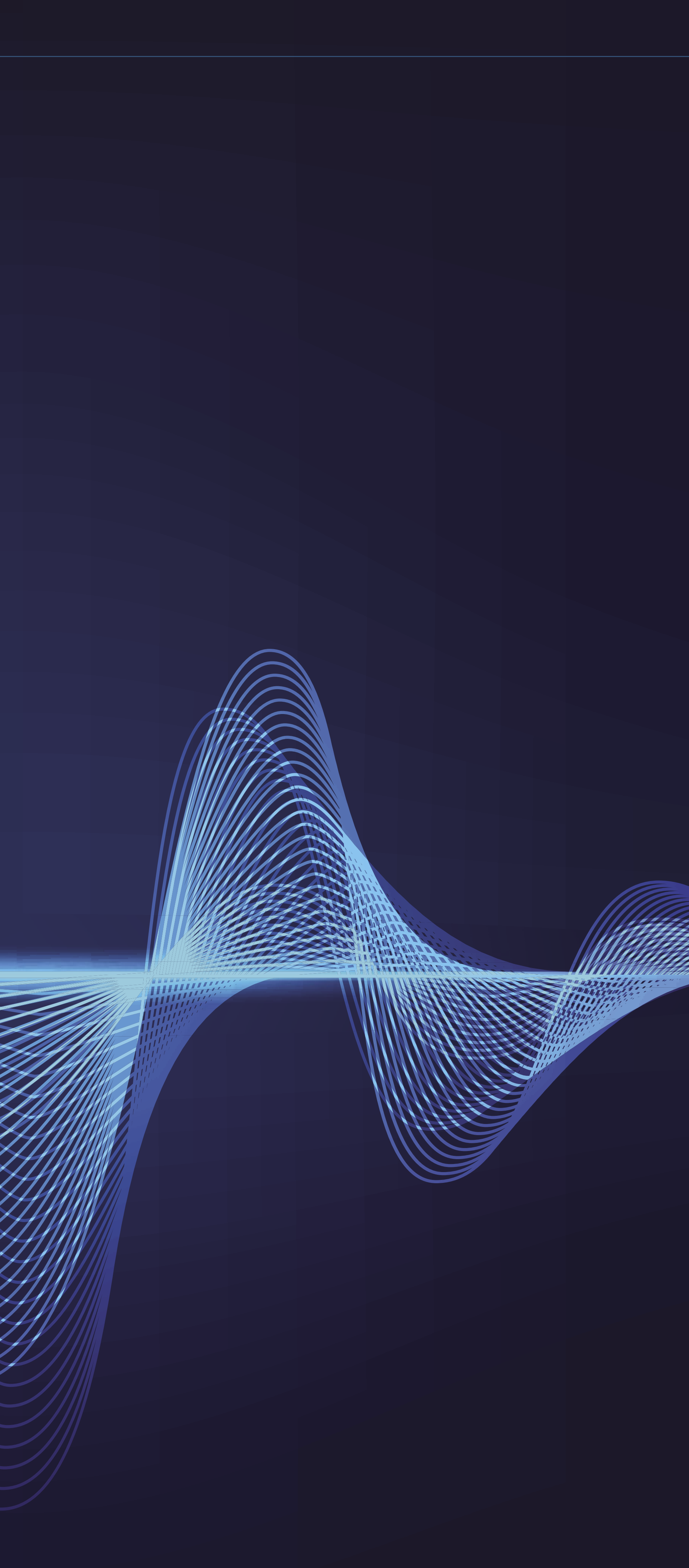
So as you can see, there's always a diverse range of interesting and exciting applications of Simcenter tools featured on our blog. And with new posts being published every day, you'll never be short of something new and exciting to discover! ■



Good Vibrations

Redefining sound and vibration testing for innovation

By Jane Wade



Sound and vibration are part of our everyday lives, much goes unnoticed, but certain sounds or frequencies can be extremely irritating and even dangerous. Think the noisy motorbike exhaust as it accelerates, the start-up of garden machinery or using a hammer-drill for long periods. It is not just loud noises that make us uncomfortable, it can be the pitch or tone, the onset, or the frequency and the subsequent vibrations. Something as quiet as a fridge, when the compressor kicks in, can cause a moment of annoyance or worse still ruin a good nights' sleep.

What are consumers demanding?
Consumers want quality and performance, what is the best product for the money I can spend? Consumers have access to online reviews, product information from the manufacturer and in many cases also factual data on sound and vibration performance. Many countries have requirements for energy consumption and sound power levels to be available at point of purchase. For items used in the workplace, think hand-held tools or heavy equipment regulations are also in place to control sound and vibration to protect the users. Consumers are in control of information to make informed choices far more so than in the past; will they choose your product?

What is the challenge for manufacturers?
Manufacturers must strive to deliver performance products and seek an advantage over other products available, across many variables, price, quality, reliability, output, power usage or sound and vibration impact. Sound and vibration optimization is complicated with increased product variants and ever more complex products. So, manufacturers are seeking to deliver on these demanding consumer requirements and comply with serious industry and regulatory constraints.

Manufacturers operating successfully in this market need to make safe, reliable, and near-silent products, but they need to develop them quickly and ensure that the finished item complies with regulation and certification relevant to the target market. This requires an agile approach, to go faster whilst still exploring many parameters involving mechanical and electrical components.

Let us start with considering the backdrop, what is different for manufacturers today compared with a decade ago?

Increased living standards

Truly a multi-faceted challenge, we are living in more open plan homes, working in more open plan offices, and living in more densely populated buildings and cities. A noisy dishwasher in an open plan living space can be a major disruption to an evening in front of the television, the fan on your laptop or the rattle of the printer can all create a challenging environment for working and impact on personal wellbeing. Skilled workers using noisy equipment, such as pneumatic drills or hammers need to be protected but also work for longer without fatigue or physical damage.

What is loud?

Environmental Legislation in a Global Market

Across the globe different countries have certification for acceptable levels on noise and vibration covering many product types, primarily with user safety in mind. Many markets also demand noise and vibration levels are explicitly mentioned on product data sheets at point of purchase.

To compete in a global economy, manufacturers not only need to be able to sell products that comply with local legislation they need to be able to bring relevant products to the market quickly. Requirements will vary from one economy to another, depending on local product usage and legislation. Compliance in one region may not mean compliance in all. How quickly and easily can that certification be completed? Manufacturers cannot have product releases derailed late in the development process.

Mass Customisations

With a large catalogue of product configurations ensuring that each variant complies can be particularly challenging and expensive. Consider a washing machine, on the same line there might be up to 15 different variants, each with different cycles, spin speeds or design features. Manufacturers must be sure each variant delivers the expected customer experience; it is not manageable to have each individual

customisation tested especially with the need to release to the market faster.

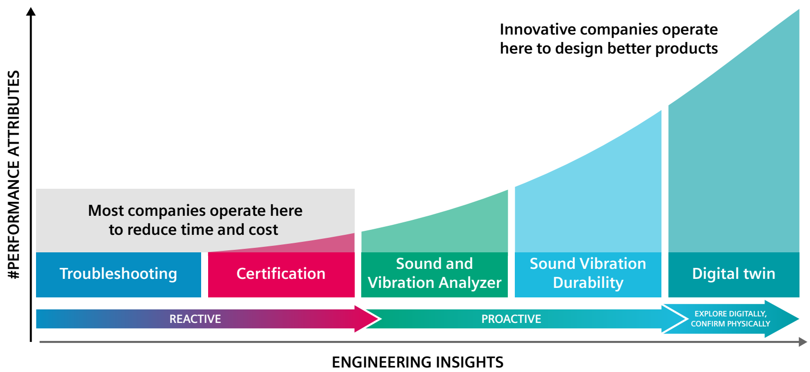
Redefining sound and vibration testing for innovation

There is a well-established continuum for improving sound and vibration levels: BLOCK, FIND, UNDERSTAND and SHAPE. We will talk briefly about them here, but the goal is to get to UNDERSTAND and SHAPE to truly deliver a world-class product. You can read more about this process in this article.

To master this process an in-house testing system which covers certification and troubleshooting is essential but only the beginning. The beginning is the reactive part of the process ensuring products are fit for purpose, that they comply with the necessary legislation and offer acceptable levels of sound and vibration comfort. To move from reactive to proactive, sound and vibration engineers need to seek genuine innovation in their product performance. This opens the opportunity for increasing market share and entering new markets.

Read More

Redefining testing strategy for innovation



Sound engineering for greater product satisfaction

To achieve the highest level of sound design, leading manufacturers invest in in-house labs that enable them to adopt smart sound and vibration strategies. The market demand for speed means there is not time to go through the continuous cycle of outsourcing to third-parties, incorporating the findings, reworking the product, and then sending back for testing, so having the capabilities in-house increases agility and decreases costs.

An efficient in-house system should include task-based software for certification and troubleshooting alongside advanced measuring methods to further the development process and to avoid last-minute reconfigurations. All data remains within the manufacturers systems, ready to be accessed for new product lines in future development schedules.

Hilti, a leading tools manufacturer are taking sound engineering to the next level. They need to develop top-quality, durable construction tools and equipment, whilst safeguarding operator health and safety. They also have a reputation to protect, they are renowned for their high-quality equipment. Releasing sub-standard products risks damaging that reputation. This is a competitive market, with manufacturers across the globe operating with different constraints and cost-bases.

To maintain brand position as a high-quality manufacturer they must ensure they follow stringent test procedures to obtain fully validated component design and given the competitive nature of the market they need to do that quickly.

Hilti have achieved the pinnacle of sound and vibration shaping using Simcenter hardware and software. They can deliver seamless test preparation, execution, and results analysis that not only supports their brand position, but also ensures validated component design resulting in greater durability and higher quality. Simcenter solutions have facilitated the development of vibration reduction technologies that have increased permitted daily use of demolition hammer by 300 percent, in addition to rapidly certifying the tool and meeting relevant vibration standards. The full story is available here

Briggs and Stratton have also taken sound and vibration beyond compliance to develop products that are smoother and quieter, tools that give the user an easier and more pleasant experience. Taking a proactive approach and building NVH (noise, vibration and harshness) goals up front in their design process working with a future-proof system, they are building best-in-class garden machinery. By analyzing sound and vibration together, they better understand the correlation and save time on testing later in the design lifecycle.

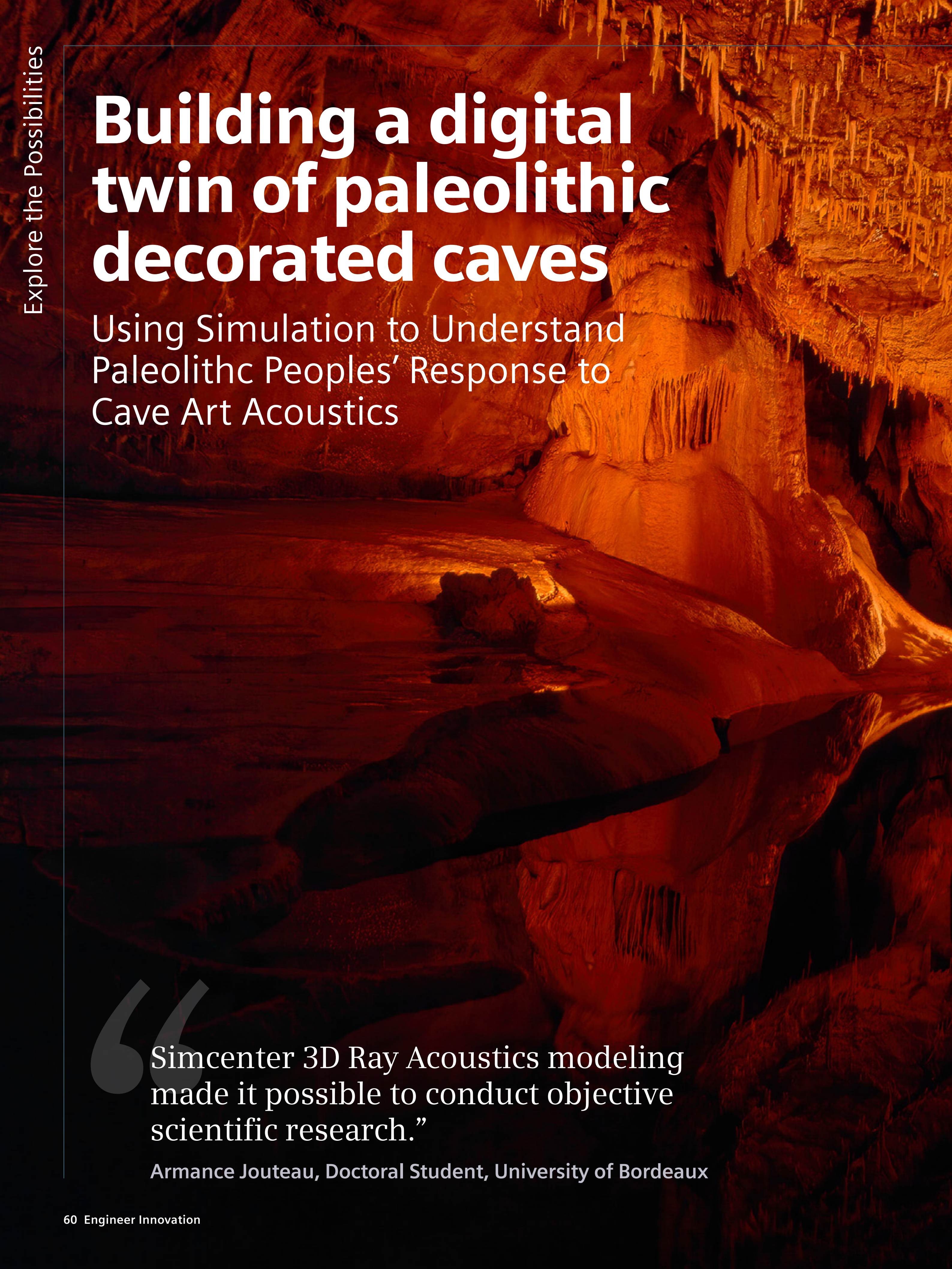
Watch Now

Read More
Full Briggs & Stratton Story

Delivering world-class products for better user experience

To follow the lead of Hilti and Briggs and Stratton, you need to develop an innovative sound and vibration approach built on solid data and in-house testing. A seamless system that can offer certification, troubleshooting and enable deeper engineering insight to deliver that outstanding end-user experience. A systematic approach avoiding guesswork and costly re-spins results in faster go-to-market, ensuring you stay ahead of the competition. Not only because the approach is better but also having a single system, start-up and training time is minimized.

Achieving this level of engineering excellence is a challenge, staying at the forefront of the market and consistently delivering better products means the approach also needs to be future proof. The system deployed by Hilti and Briggs and Stratton ensures their operators can complete certification or repetitive tasks using predefined templates, but they also investigate designs fully to obtain detailed engineering insights. Those insights that allow them to develop products that keep them at the forefront of their markets. ■



Building a digital twin of paleolithic decorated caves

Using Simulation to Understand Paleolithc Peoples' Response to Cave Art Acoustics

> "Simcenter 3D Ray Acoustics modeling made it possible to conduct objective scientific research."
>
> **Armance Jouteau, Doctoral Student, University of Bordeaux**

20,000 years ago, the paleolithic inhabitants of what is now known as the Dordogne region of southwestern France began painting on the walls of a cave in which they lived. The Lascaux cave paintings, over 600 images of large animals and fauna are the most famous in the world, but little is known about the paelothic people that created them, or how they used the cave space. To unlock this ancient mystery, researchers have turned to Simcenter

Doctoral student and researcher Armance Jouteau at the University of Bordeaux, PACEA Ministry of Culture Laboratory, is studying the use and organization of art in paleolithic decorated caves at Lascaux and Cussac. She is taking a different approach by using acoustic data with software simulations to better understand how paleolithic people understood their subterranean environment.

Even though archaeologists have some measurements of acoustics in caves, the conclusions about paleolithic peoples' responses to sounds traditionally have been based mainly on the perceptions or ideas of the researchers. Armance wanted to contribute information to the field so that she and her fellow researchers could be assured that observations and conclusions are not based solely on their feelings. She wanted to produce objective data that can be shared across and inform research projects in the future.

Determining the Connections between Space, Light, and Sound

Her research focused on data of how people might have localized themselves as the sound moved within the cave. Sound would have been the primary way of mapping out their position inside the cave. Light sources were limited in coverage and duration compared to the lights we use today. Armance also wanted to see if they could identify a connection between the location of the major structural pieces and artworks in the caves to the places where the sound is better. Researchers had in the past proposed a direct link between these two things but it had yet to be proven.

They first recreated the cave structure digitally, as it would have been several thousand years ago. For Cussac, it was easier because the

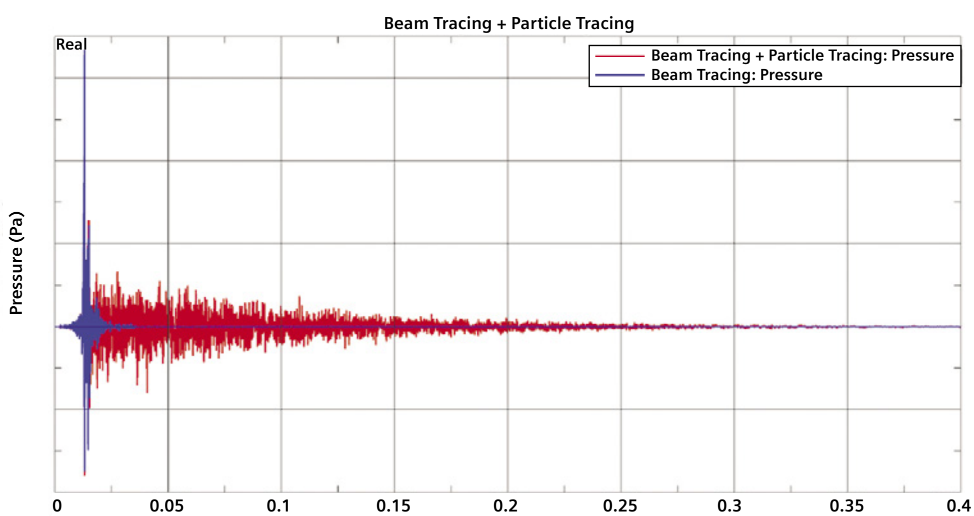
cave has not been altered much. In Lascaux, however, many modifications have been done since it was rediscovered, especially above ground. As part of the efforts to recreate the paleolithic ground, another research project is working on deducing the original morphology of the Lascaux cave before it was discovered, as well as during paleolithic times.

The conservation efforts of the Lascaux cave that limit entrance make it impossible to do standard test and measurement. Standard equipment would be disruptive to the cave so the only way to do this kind of research is through simulation, through building a digital twin of the cave.

To measure the cave's shape today to approximate the way it was thousands of years ago, they first replicated the morphology just before the discovery in 1940, based on data from the archives, photographs, people testimonies, reports, books, and archaeological studies. Starting from this morphology of the discovery, they then wanted to be able to interpret the paleolithic times based on mainly geological, morphological, and archaeological data rather than assumptions or feelings.

The goal of Armance's thesis is to use modern simulation tools to better understand the way people from these periods were living, how and perhaps why they painted things in relation to the way they were locating in the dark. It is probable that acoustics were just as important as light underground.

They used Simcenter to conduct ray acoustic modeling, approximating sound as a beam instead of a wave. Inside the model, they placed a virtual microphone and headphones in key places from an archeological point of view. Then, they ran the sound simulation and analyzed the data, which can be in the form of an acoustic response or sound pressure changes. Nicole, at the Centre Scientifique et Technique du Batiment (CSTB; Scientific and Technical Center for Building), who works with software to simulate sounds and lighting in buildings, helped the researchers to build the model for use in Simcenter's digital twin.



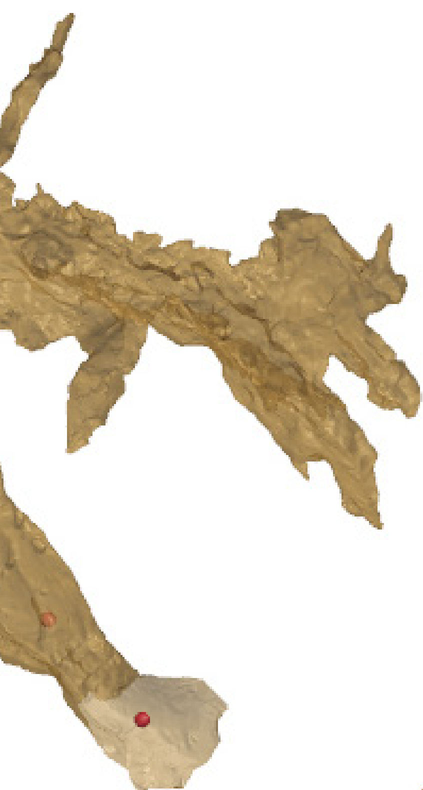
First left:
3D model of the cave in Simcenter 3D. Geometry courtesy of Laboratory Cave of Leye.

Second left:
Simulated impulse response between two humans in the cave.

"With Simcenter, we are able to simulate the acoustic behavior of the Lascaux cave in its Paleolithic shape in very fast simulation times. This allows us to study whether primitive men may have used echolocation to move inside," says Armance.

Simcenter tools are enabling the building of digital twins that merge data from the virtual and real world, blurring the boundaries between engineering and process domains, even as Armance is crossing the domains between archaeology and building technologies.

Simcenter is built to deliver multi-discipline simulation inside a centralized engineering desktop, and Simcenter's simulation solvers help predict real-world performance for various physics domains. Simcenter 3D's new ray acoustics solution treats high frequency sound behavior as if it were a ray of light. It simulates sound propagation by tracing beams of sound shooting from a monopole source and reflecting when striking surfaces. Simcenter is ideal for simulation of the paleolithic caves because it is designed to simulate very large geometries and higher frequencies.



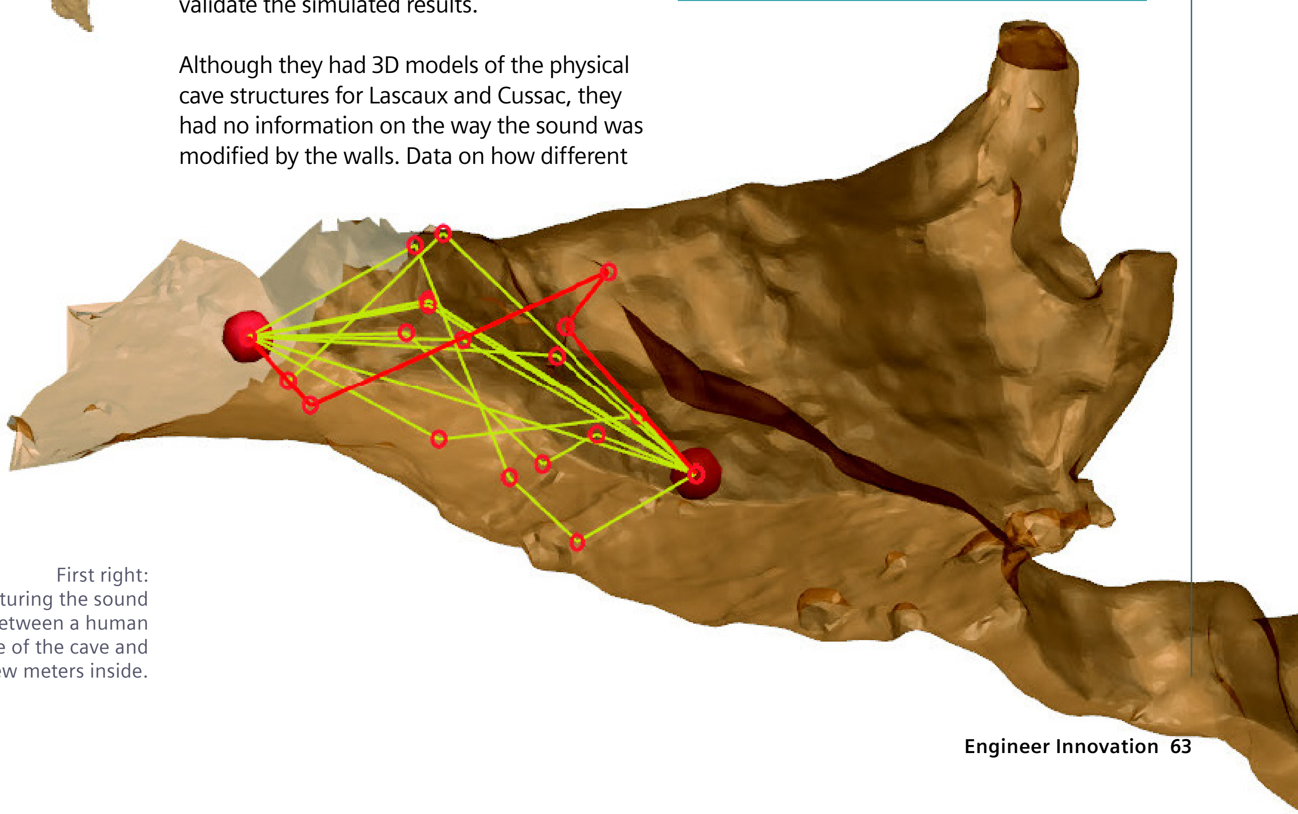
Armance and her team validated the simulation results by collecting data from the Cussac cave and the Leye cave in Dordogne, France, which they used as a standard "laboratory" cave because it has no archeological equipment. They could then compare the direct-measurement results to validate the simulated results.

Although they had 3D models of the physical cave structures for Lascaux and Cussac, they had no information on the way the sound was modified by the walls. Data on how different materials would return sound was not readily available, such as the variations of types of stone and clay in the caves. So they had to take measurements in the real caves by sending sound and collecting the data on how the sound was modified by the particular wall materials and by the shape of the caves.

The fed the many different measurements they collected to the model, then ran simulations and compared the results to the measurements they took in the cave. They can then apply the same method with other paleolithic caves, which are much more difficult to gain access, once they validated the data for simulations with direct measurements.

Armance says, "Based on this paleolithic morphology, we wanted to create simulations and try to recreate the acoustic response in the Lascaux cave at the paleolithic time. I was particularly interested in using simulation to recreate and try to understand this paleolithic response. Thanks to the simulation, we are able to understand, to hear, what was the acoustic response heard by paleolithic people." ■

Learn more here
For more information and details, see the technical paper "Understanding the Perception and Appropriation of Space In Palaeolithic Decorated Caves: New Methods and Tools, with the Examples of Cussac and Lascaux Caves," by Armance Jouteau, Valérie Feruglio, Delphine Lacanette, Samuel Carré, Nicolas Noé and Jacques Jaubert, published in Rock Art Research (2020), Volume 37, Number 2.



First right:
Ray paths capturing the sound propagation between a human at the entrance of the cave and another one a few meters inside.

Quit whining!

Are e-bikes too loud?

By Frank Demesmaeker

How did you celebrate World Bicycle Day this year? As a keen cyclist, I just had to get out on my bike. I'm one of many people across the world who have recently invested in an e-bike and, let me tell you, they make riding even more fun than usual.

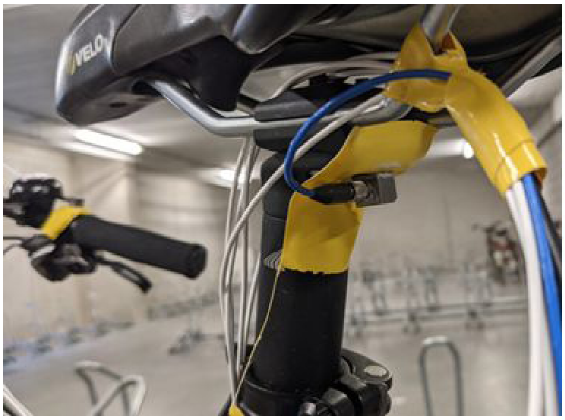
For the uninitiated, an e-bike is a conventional bicycle with a motor powered by a rechargeable battery that supports your pedalling power, allowing you to go much further before you get tired out.

Cycling purely for pleasure is great, but as I'm an engineer I'm intrigued by how these modern bikes work and so I decided to carry out some tests whilst I got some fresh spring air and exercise.

Naturally, one of the key elements of an e-bike is its operating range – how long the battery lasts. You can already find plenty of studies and statistics on battery performance, so I wanted to look at another important aspect of the e-bike that gets far less attention.

How much noise does an e-bike make?
Motors make noise, there's no getting away from it. Sure, these motors are very small compared to those you'd find in a car, but they're still not silent. You can assess the noise generated in decibels with a sound level meter, but I wanted to understand more than that – what is the overall sound and vibration comfort that e-bike riders experience ?

To do this, I needed something that was small enough to carry on my bike, yet powerful enough to capture all the data I needed. The Simcenter SCADAS XS is a handheld device designed to give full flexibility for noise and vibration testing so it was perfect for the task. It has 12 input channels so as well as using its binaural



headset I attached the following sensors to my bike to capture as much data as possible:

- Seven accelerometers at different locations covering all the main parts of the bike: handlebars, suspension, saddle, frame,
- Wind screened microphone close to the electric motor,
- GPS signal for speed, position and altitude, and
- GoPro camera to keep a visual record of my journey.

With the sensors and cables securely taped to the bike frame I could simply switch the Simcenter SCADAS XS on and slip it into my backpack, whilst monitoring the data from a wirelessly connected tablet. All the data is saved on the internal memory card inside the Simcenter SCADAS XS and its internal battery gives a full day of riding without worrying about running out of power. All I had to do was pedal away (with a little boost from the electric motor) and let the Simcenter SCADAS XS record all the noises and vibrations as I went over different surfaces and up and down hills.

Analysing the data
I had a great ride, but the fun really began afterwards when I looked at all the data I'd recorded.

First, I used Simcenter Testlab Neo to generate a visual representation of the noises and vibrations captured. It's a really intuitive tool which allows you to easily select the sensors in the pivot table and then automatically adds the corresponding signals to create an event image of your journey.

Watch now

See how the software also allows you to combine video from the GoPro and GPS data to make it easy to see the exact point that each event occurred? Pretty cool, I think!

Did you feel that?
Here in Belgium, cobblestone paths are rather popular. I already knew that they are more uncomfortable to ride over than a smooth path, but I wanted to understand just how much difference it makes.

The vibration data collected from the sensors attached to the Simcenter SCADAS XS can be used to visualise frame and suspension deformations, and to quantify the ride comfort using ISO human body vibration standards.

Using the measured vibrations on the frame with time domain animation and operational model analysis I created an animation of what was happening during my ride.

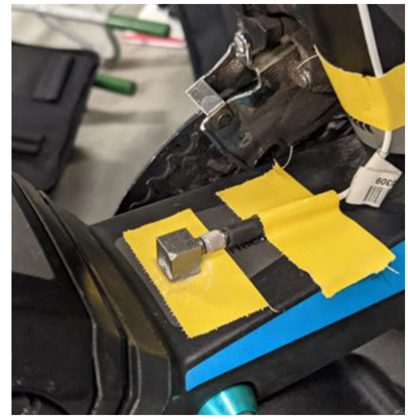
Watch now

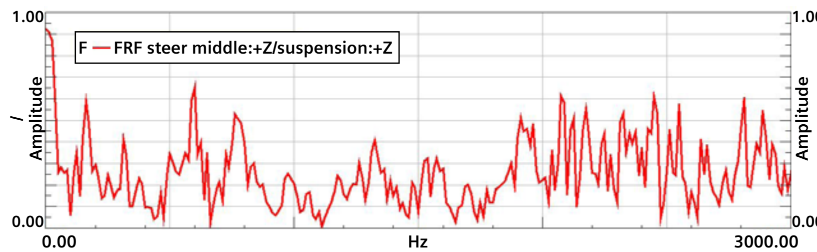
Then from the measured vibrations on the front suspension I created a graph characterising the damping efficiency of the suspension as a function of frequency.

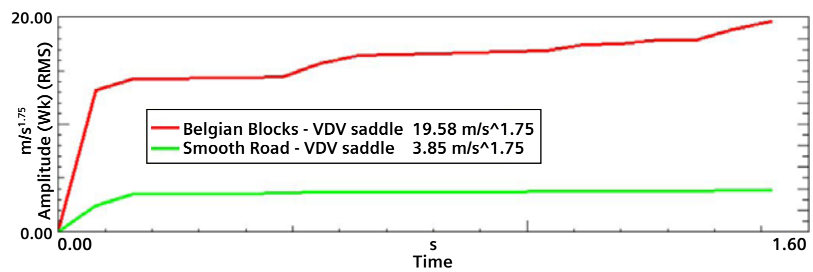
And using the handlebar and saddle vibrations I produced an evaluation of ride comfort based on ISO2631 human body vibration standards.

As you can see, it's clear that riding on these Belgian Blocks is considerably less comfortable than riding on a smooth road.

What's that noise?
Before investigating the sound produced by







the motor itself, I had to understand how much noise was generated by the road surface. I cleaned up the data collected from riding over both cobbled and smooth paths using sound quality metrics such as Articulation Index, Prominence Ratio, and Time Varying Loudness as well as adding traditional SPL and Spectrum analysis.

Watch now

As you'd expect, the noise generated by the cobbled surface masked the whine of my electric motor. The prominence ratio for the smooth road measurement was 2 dB higher, but all the other metrics reported that the cobblestone road had a very negative impact on my acoustic comfort.

However, the problem with conducting a test like this in a public space on a sunny spring day is there were lots of other people and animals enjoying the weather and generating extra noise. So, to do a really thorough acoustic assessment I needed to

collect some extra measurements in a controlled environment.

Fortunately, I have several colleagues who are equally enthusiastic cyclists so I asked three of them to bring their e-bikes so we could benchmark them alongside mine.

All the bikes sound different, despite three having the same motor, but that's because it is integrated differently in each one. And the initial tests showed that one bike was generating some unusually strong high-frequency noise.

Watch now

After using the interactive audio filtering, it became clear what the issue was – the bike was suffering from a prominent break squeal noise, with peak amplitudes around 12.500 Hz. This might not be a concern for everyone though, as it's common for anyone over the age of 50 to be unable to hear high frequency noises such as this.

Watch now

But to make a fair comparison of the motor noise it was important to filter out the break squeal which resulted in an impressive 15 dB drop in the prominence ratio. Now the playing field was levelled, the clear winners were bikes B and C which had high articulation index values, prominence ratio at around 7.5dB and 9 sones of loudness. Bikes A and D, however, affected speech intelligibility and resulted in higher loudness and tonality levels.

Watch now

Is this accurate?
Of course, no matter how much you can prove with equipment and data, it's important to confirm your findings by conducting a subjective listening test. Jury Testing collects feedback from a group of listeners to understand their preference towards one sound or another. This is crucial when benchmarking against competitors, designing new sound quality targets (how much loudness is too much), or creating combined sound quality metrics that represent a certain product feature (pleasantness, robustness, sportiveness etc)

Watch now

In this example a randomly created pair of sounds is played to the juror and they are asked to answer the question "Which of these e-bikes would you take on a long ride?". They are given a 5 point scale (as per Sheffe's method) to allow for more freedom in their answer:

- Definitely A,
- Rather A than B,
- Either would be fine,
- Rather B than A, and
- Definitely B.

Normally this would be repeated several times with several jurors, and a ranking produced at the end for the most to least preferred. Unfortunately, due to COVID-19 restrictions, we weren't able to organise these tests, but rest assured, we will when it is safe to do so as I'm eager to confirm my findings!

Great thing come in small packages
It's amazing how much analysis you can carry out with the data collected from the handheld Simcenter SCADAS XS, don't you think? ■

If you want to discover more, watch our webinar or take a look at how Agfa Graphics have used it to optimise their printing plates.

Brownian Motion...

The random musings of a Fluid Dynamicist

Why Failure IS an Option!

My favourite quote, from my favourite movie, comes from Ron Howard's 1993 docu-drama "Apollo 13".

As Gene Kranz (wonderfully played by the actor Ed Harris) addresses a crowd of NASA engineers and flight controllers he implores them to find a way of bringing the crew of the recently crippled spacecraft safely home:

"We're gonna have to figure it out. I want people in our simulators working re-entry scenarios. I want you guys to find every engineer who designed, every switch, every circuit, every transistor and every light bulb that's up there. Then I want you to talk to the guy in the assembly line who had actually built the thing. I want this mark all the way back to Earth with time to spare. We never lost an American in space. We're sure as hell not gonna lose one on my watch! Failure is not an option!"
Gene Kranz – NASA Flight Director

Gene Kranz is one of my heroes, and the Apollo 13 story is one of the greatest stories of engineering triumphing over adversity. I once had the pleasure of meeting Kranz at a conference and hearing him speak. In real life, he is every bit as inspiring as his movie caricature.

However, as a middle-aged engineer, I respectfully disagree with him on the "failure is not an option" thing. In my life and my career, repeated failure is a necessary condition for eventual success.

Put simply, if failure is not an option, then neither is success.

Failure is the very fabric of innovation; it's what success is made from. At its heart engineering is a process of continual improvement. Engineers take existing things and try to make them better, usually by making a series of incremental changes, each intended to make a product somehow "better": faster; stronger; lighter; more efficient; less expensive. Every successful product results from many design iterations, each of which gradually improves the product's performance in some manner.

The problem is that for every successfully implemented design improvement, there are many more "failed iterations". Those that either delivered no improvement in product performance or somehow made it worse. For every hard-won improvement in product performance, there is an almost infinite number of ways to break it.

Predicting which changes will improve a product, and which will diminish it, is the art of engineering; we have to identify

poorly performing design choices so that we can eliminate them. Often the lessons that are learned from early failures influence the whole future design direction of the project.

In the good old days of engineering, this process of improvement through repeated failure was almost entirely dependent on the (sometimes destructive) testing of physical prototypes in a process that was often described as “design, build, test, repeat”. Because those prototypes were expensive and only available late in the design process, opportunities for failure (and therefore innovation) were severely limited.

We are very fortunate to be part of a generation of engineers that can deploy accurate simulation and enormous computing power, to tell us which design changes work, and which design changes fails, across hundreds or even thousands of possible design iterations.

Of course, I’m being unfair to Gene Kranz. He understands more than anyone that success is dependent on learning from your failures. Kranz’s first mission as NASA Flight Director was the ill-fated Mecury-Redstone1 launch that rose a total of four inches in the air before exploding in mid-air. He credits the disaster that tragically claimed the lives of three American astronauts on Apollo 1 as the most significant event of the Apollo program:

“It was perhaps the defining moment in our race to get to the moon. The ultimate success of Apollo was made possible by the sacrifices of Grissom, White, and Chaffee. The accident profoundly affected everyone in the program.”

Consumers imagine that beautifully designed products are conceived fully formed from the mind of a brilliant designer without recognising that all products evolve through multiple failures.

As engineers, we rightly take lots of pride in our successes, but I think that we all need to spend more time recognising the amount of “grunt work” that goes into designing beautifully engineered products. But we need to talk more about failure.

Rather than adopting the macho “Failure is not an option” approach, I think that the engineers need to be more honest about their failures and adopt the following mantra:

“Fail early. Fail often. Learn from your mistakes and share them with others.” ■

“We’re gonna have to figure it out. I want people in our simulators working re-entry scenarios. I want you guys to find every engineer who designed, every switch, every circuit, every transistor and every light bulb that’s up there. Then I want you to talk to the guy in the assembly line who had actually built the thing. I want this mark all the way back to Earth with time to spare. We never lost an American in space. We’re sure as hell not gonna lose one on my watch! Failure is not an option!”

Gene Kranz – NASA Flight Director

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