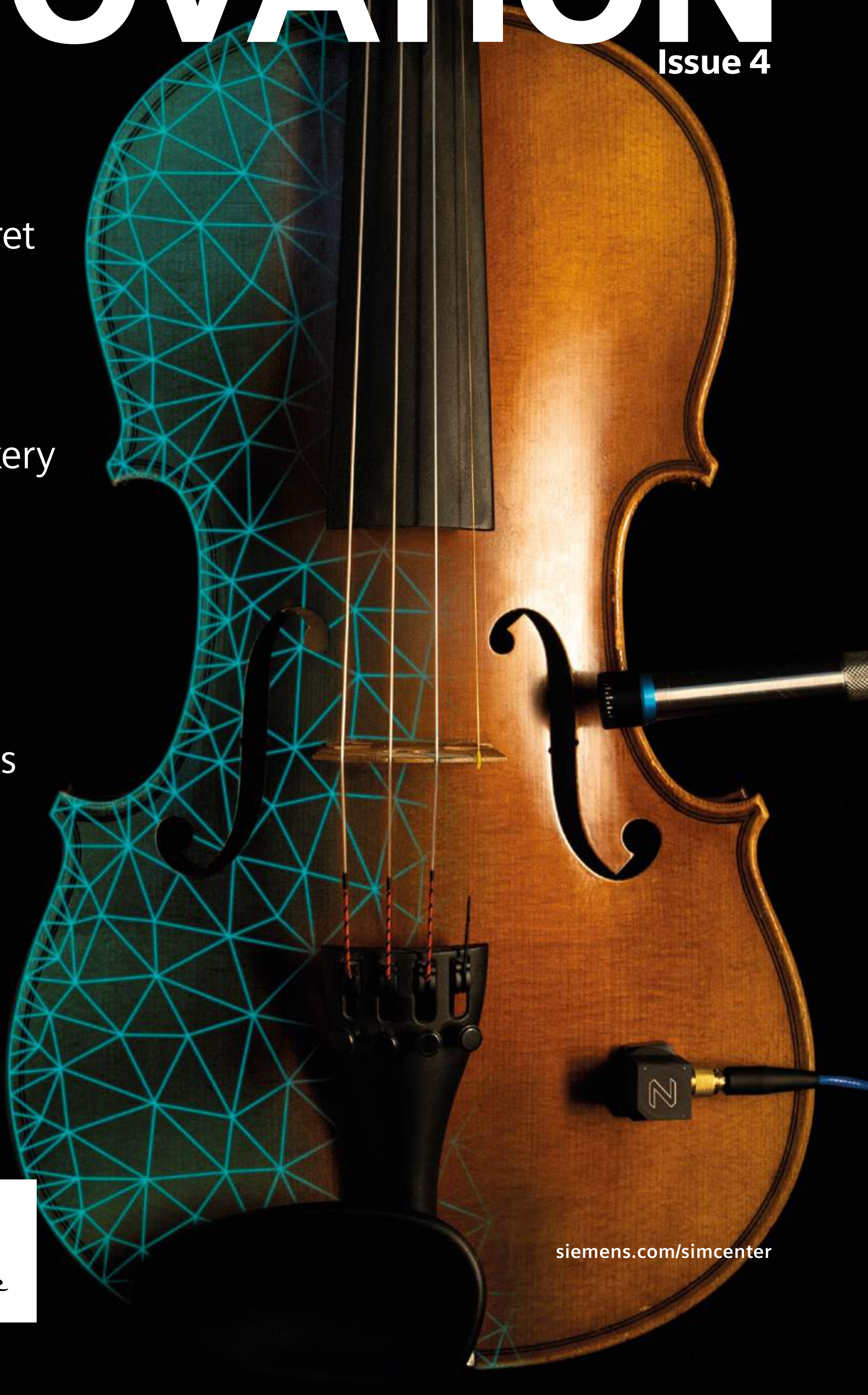
Engineer

INNOVATION

Issue 4



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Personally speaking

Siemens PLM Software

Jan Leuridan
Senior Vice President
Simulation and Test Solutions

The digital twin continues to proliferate and is a concept often associated with Siemens, and given our investment in software, additive manufacturing and the digital industries, this is good news indeed. But sometimes these terms can be too ethereal and my interest is piqued when I see this concept in action.

Within the high-tech sector we see many themes emerging and personalization is increasingly at the forefront, this can be at odds with mass production and globalization. What role does Simcenter play in creating that personalization within the digital twin environment? As I read another selection of success stories from our customers I see again and again how that theme is realized.

Breaking human speed records is a very personal process, the hours of dedication and training are beyond most of us, but the recent sub-2-hour marathon was possible because of simulation and developing a digital twin. We delve deeper into that process in this issue to understand how personal dedication can be augmented by technology.

The shift to more on line activity, particularly with personal shopping, presents a new challenge with many, much smaller deliveries than previously. That last mile is the most expensive part of the delivery journey, autonomous robots may hold the answer and the team at TwinswHeel have been working with Simcenter to deliver on that possibility.

There can be nothing more personal than sleep, good quality sleep can be a rare occurrence and therefore minimising noise pollution is of paramount importance. Our testing team have been reducing the impact of wind turbine noise, a power generation method that increasingly contributes to our energy demands.

We often think of the digital twin as only impacting the modern but the cover story takes a look at how it can be used to replicate the ancient and revered, recreating the sought after sound of a Stradivarius.

From the ancient Pythagorean Cup to the ultra-modern rocket launchers, all with Simcenter and all in this issue of Engineering Innovation. ■

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Regular Features

Unveiling the secrets of violins

Associazione Liutaria Italiana

Simcenter testing solutions and digital twins help reveal the data behind the sound.

Every single violin – from a priceless Stradivarius to the violin a beginner plays in the school orchestra – has a unique personality. Besides subtle differences in the instrument itself, such as shape and form, varnish, age, wood types and manufacturing processes, string instruments are influenced by the musician's individual technique as well.

What is the secret to creating a stellar sound? What makes priceless violins so exceptional that virtuosos clamour to play them? Genoa, Italy is the home of Il Cannone, a heritage violin dating from 1743, and an unusual team of violin researchers.

Professor Enrico Ravina and engineer Paolo Sivestri have been researching the acoustic performance of violins and string instruments for more than a decade, using a variety of Simcenter™ software simulation and testing tools to explore the data behind the sound. To gain insight into the construction process, Pio Montanari, master violin maker, joined the research project as did Pier Domenico Sommati, second principal violinist at the Genoa Opera. Although not researchers, both Montanari and Sommati provide the hands-on experience and expertise required to help pinpoint what this novel research work will mean for the future of violinmaking and violinists around the world.

Art or science?

Although Sommati normally plays a violin dating from 1781 from Vincenzo Carcassi from Florence, he was more than eager to play one of Montanari's latest models for the test run. Using a customized sound array running Simcenter™ SCADAS™ hardware, test expert Sivestri collected unique acoustic data from Montanari's new handcrafted violin as well as heritage data from a 1781 violin.

"Very old violins are very different in the way they are constructed," Sommati explains. "It is quite a different world. New violins have their own positive acoustic effects. A new instrument is not necessarily going to sound worse than an antique one. You just have to get used to the instrument that you play."

"The goal of our project is not necessarily to reproduce classic violins, but rather to learn the secrets behind a certain type of acoustic performance," says Ravina, a full professor at the Polytechnic School of the University of Genoa and a member of the governing council of Associazione Liutaria Italiana (ALI - the Italian Association of Stringed Instrument Makers). "This might be the wood, the way it is constructed, the way it was repaired, the layers of different varnishes over the centuries, or how it was stored or used. The number of possibilities that affect a certain type of violin sound isn't necessarily a science. It is more of an art, and we are trying to discover the engineering behind this art to help violin makers create the best possible instruments today as well as offering a pool of research information for future restoration purposes."

The data behind the sound

As the testing team and Montanari looked on, there was a tremor of magic in the air as soon as Sommati's bow struck the strings of Montanari's violin. Where did this magic come from? Where is the science behind the sound?

"I try to put something new into every instrument I make," says Montanari. "We have been working with Professor Ravina for over ten years and I have really focused on precise elements of the acoustics." Typically, it takes Montanari one month to finish a violin and several more weeks to varnish. He has made more than 100 violins in his career although he quickly notes that he spends a lot of his time repairing and adjusting instruments as well. At the moment, he has a special signature

> *"It is important to know the characteristics of a historical instrument to construct a good replica. This is why our work with Simcenter and Siemens is so useful."*

Professor Enrico Ravina
Polytechnic School, Università di Genova
ALI Associazione Liutaria Italiana

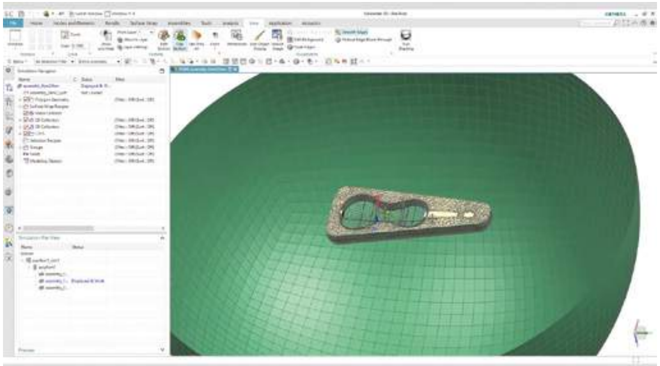
technique that includes varnishing with his fingers, which means, he quips, that he can save money not buying brushes.

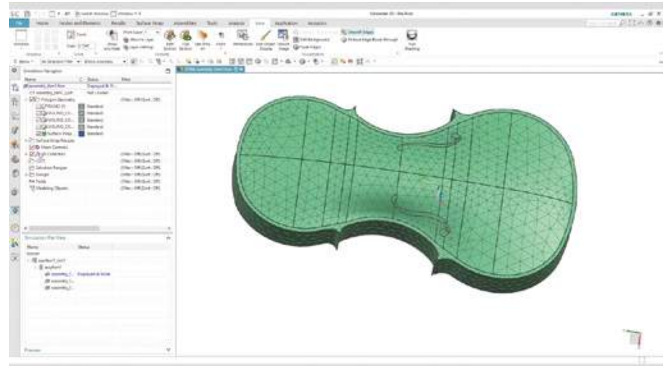
"A master violin maker like Pio Montanari has to consider many different shapes today," says Professor Ravina. "Not every violin is going to be a Guarneri or Stradivari. It is important to test different types of shapes and learn what effects they can have on the overall sound. With a scientific project like this, you see the data behind the sound."

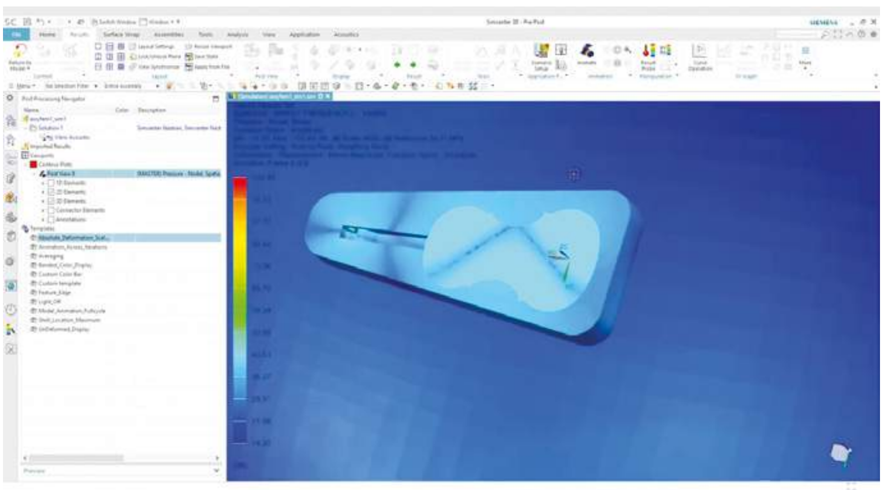
From MUSICOS to ALI

This research project did not evolve overnight. With the subject close to his heart, Professor Ravina started working on this topic more than a decade ago as part of the former MUSICOS organization, the Multidisciplinary Research Centre for Choral and Instrumental Music, at the University of Genoa. The activity of the former MUSICOS center ended in 2013, but Professor Ravina continued the research project at ALI which is based in Cremona, the home city of Guarneri and Stradivari, among others. ALI is directed by Professor Lucia Maramotti, a restoration expert. Within the ALI organization, there are several groups of researchers studying different issues of stringed instruments.

The project that Professor Ravina leads is oriented towards testing the vibrations and acoustical responses of instruments. "For more than a decade,







tools like Simcenter™ Testlab™ software and Simcenter SCADAS hardware have been very useful to study an instrument's behavior to gain information from a vibrational and an acoustic point of view," adds Ravina.

One of the key aspects that the researchers still appreciate is the high-quality analysis capability of Simcenter testing solutions. For more than a decade, the team has been gathering quality data by performing modal analysis using Simcenter SCADAS hardware and analyzing it in Simcenter Testlab software. Using this seamless setup, the team can dive into the data and investigate the optimal design and performance of violins and other stringed instruments to improve the acoustics of future instruments and help restore ancient violins.

"To create a methodology that supports quality string instrument manufacturing is a huge advantage for the high-end market," says Professor Ravina. "The fact that our work covers the restoration of classic instruments also makes our partnership with Siemens even more rewarding."

The digital twin and the violin

More than a decade later, the project has progressed from modal analysis using the Simcenter testing solutions to a complete digital twin study. The team links the valuable data sets that they have accumulated over the years seamlessly into digital twin models for further analysis work. The latest digital twin is a model of a Montanari violin, created in NX™ CAD software, which can be further studied in Simcenter™ 3D simulation software to explore the effects of the various acoustic data sets. Potentially, it may be possible to create digital twins of priceless heritage violins for research purposes.

"With Simcenter 3D, we can quickly validate the importance of a test setup and explore other acoustic possibilities that we might not have thought about in a traditional setup," Professor Ravina says. "Technology like Simcenter testing solutions and Simcenter 3D simulation can play a significant role in

understanding the sound patterns and real behavior of musical instruments in general, and in particular the violin family. We have done some of our own innovating on the test setup side as well."

A customized sound array
One example is a customized sound array in which the musician is surrounded by 10 distributed microphones on an arch. This setup is used to create a sound map of the acoustics created by the instrument in Simcenter Testlab. From there, Simcenter Testlab software can easily create a spherical mapping, giving information not only about the sound power of the instrument but also the directivity.

"Our low-cost sonic arch system is really purpose-built," adds Professor Ravina. "The idea is to have the violinist in the best possible position to correctly map the sound generated by the instrument."

Streamlined test setup
Besides built-for-purpose arches, another key factor to the success of the test setup is the ease and portability of Simcenter SCADAS hardware. Testing experts like Sivestri can simply take the 16-channel Simcenter SCADAS data acquisition system out of its carrying case and set it up. This makes it easy to install a test setup offsite in workshops or perform tests on historical instruments in museums.

"It is important to know the characteristics of a historical instrument to construct a good replica. This is why our work with Simcenter and Siemens is so useful," explains Professor Ravina. "It is easier to move the software and test instrumentation than to move a famous violin like Il Cannone."

The beginning of the digital journey
Both Professor Ravina and Montanari are quick to point out that this is just the beginning of the digital journey for the ancient profession of violin making. Both experts are certain the research work will have an impact on both traditional handcrafted models and more mass-produced string instruments.

"You need to define the characteristics of old and famous instruments to make good replicas," Professor Ravina explains. "Our methodology supports the construction of the replica step-by-step using experimental and

theoretical analysis. Our research is important because the violin maker requires specific information and many times this information is not available. This is why it is so important to have portable instrumentation like Simcenter SCADAS hardware and Simcenter software. They are easy tools to manage to have a prompt response for the violin maker during the construction of an instrument."

"It is very difficult to imagine what will happen in the future of violin making because of this technology helping us today," Montanari adds. "Even as technology becomes more available, we have to maintain a sensibility that violin making is about personal construction. We don't want to forget that we have fingers and the ability to listen to a sound."

In the future, Professor Ravina hopes to continue to share his work with other experts on an international level. "As researchers, we don't have the knowledge of the construction or techniques," Professor Ravina says. "Our long-term partnership between the university researchers, the violin makers, the violinists, and Siemens Digital Industries Software has been very important, interesting and exciting. Looking forward, we are part of several international projects and I hope this will continue as well. It is very important and useful to compare results with other researchers and experts on an international scale." ■

"For more than a decade, tools like Simcenter Testlab software and Simcenter SCADAS hardware have been very useful to study an instrument's behavior to gain information from a vibrational and an acoustic point of view."

Professor Enrico Ravina
Polytechnic School, Università di Genova
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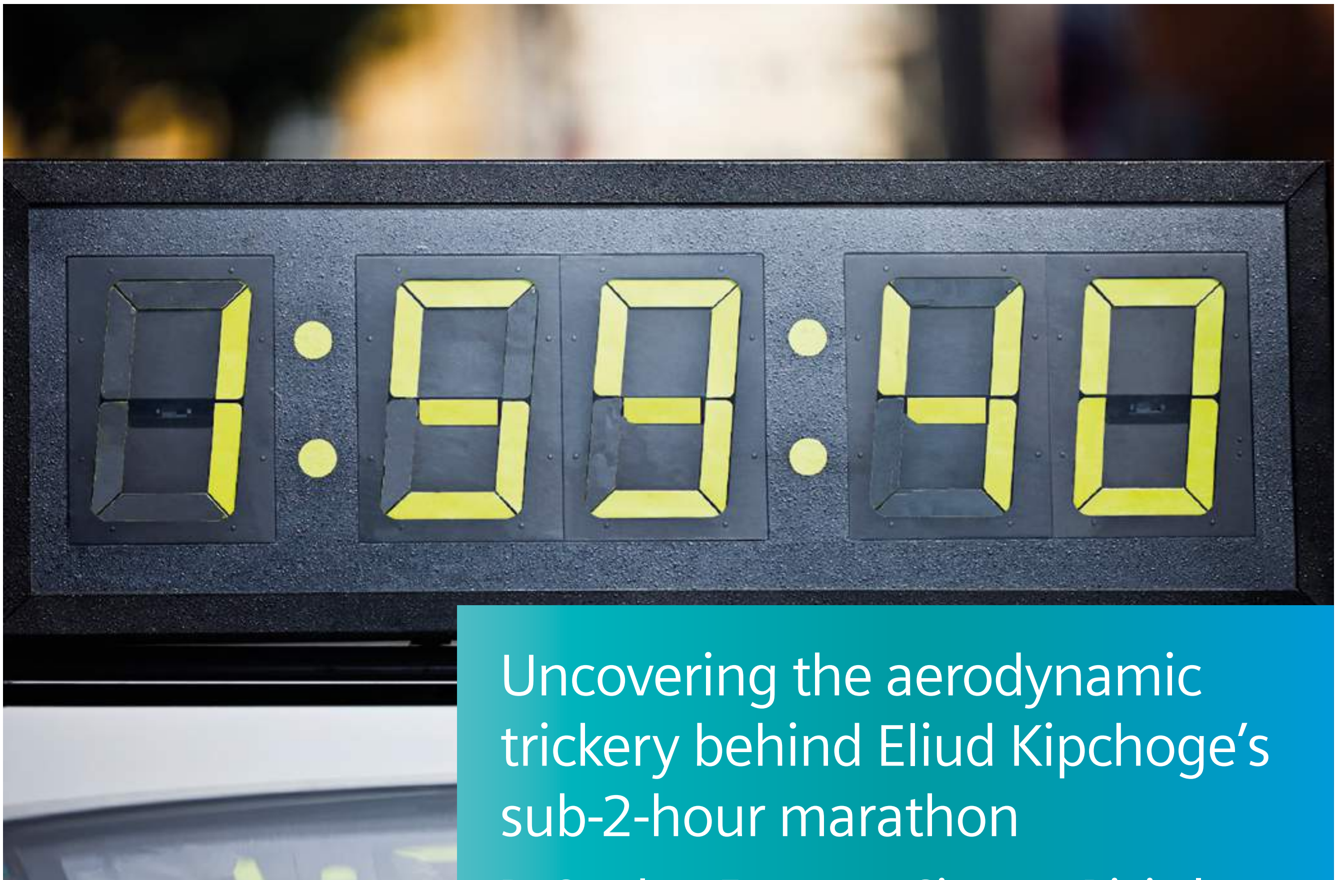

Uncovering the aerodynamic trickery behind Eliud Kipchoge's sub-2-hour marathon

By Stephen Ferguson, Siemens Digital Industries Software

CFD simulations by Christopher Beves, and Prashanth Shankara, Siemens Digital Industries Software

In the early hours of Saturday, October 12, in Vienna Austria, Kenya's Eliud Kipchoge ran 26.2 miles in 1 hour 59 minutes and 40 seconds, becoming the first human to complete the marathon distance in less than two hours. In the process, Kipchoge took down the biggest mythical barrier in the sport since Roger Bannister broke the four-minute mile at the Iffley Road track in Oxford, some 65 years ago.

However, despite running two minutes and one second faster than his own world record (2:01:39, set at the Berlin Marathon in October 2018), Kipchoge's historic sub-2-hour effort will not be formally recognized as a new world record by the IAAF; the INEOS 1:59 project deliberately employed a number of tactics, as citied in Science magazine in May 2017 [1], that meant his time is not recognized as a legitimate world record. I don't want to go into too much detail here, but the team apparently applied a "scientific" approach to optimizing every part of his kit, training, nutrition, and race tactics.

The INEOS 1:59 project was Kipchoge's second attempt at breaking the 2-hour barrier, a spiritual successor to the Nike Breaking 2 project which took place on May 2017 at the Monza motor racing circuit in Italy, at which Kipchoge was agonizingly just 26 seconds (less than a second per mile) away from breaking the two hour barrier.

In order to determine just how much influence "aerodynamic trickery" had in getting Kipchoge within 26 seconds of the mythical 2-hour barrier we decided to run some CFD simulations using Simcenter STAR-CCM+™.

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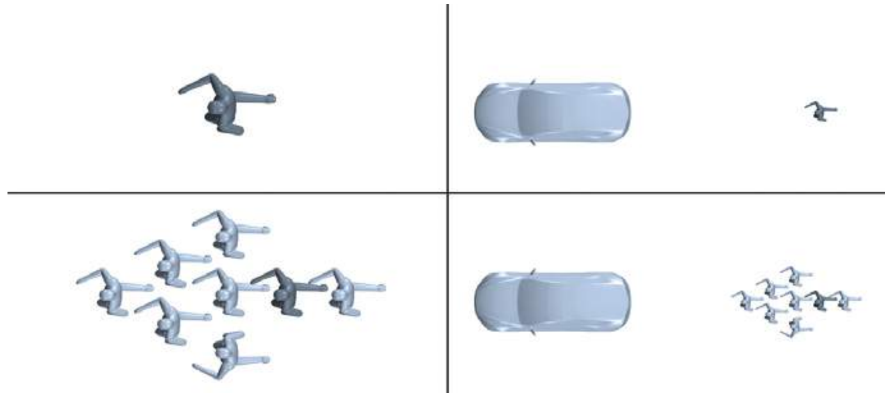

Figure 1: Breaking 2 simulation scenarios

Nike Breaking 2: 2:00:23
Before the run, much of the publicity had focused on Nike's spring-loaded Vaporfly Elite running shoe [2], which they had claimed improves running efficiency by as much as 4 percent. However, in the days afterward, much of the conversation turned to aerodynamics, and the influence of the unfeasibly large timing board that was mounted on top of the pace car that drove in front of Kipchoge, and the "delta formation" adopted by his team of "relaying" pacers. By some calculations [3], drafting was responsible for about 1 minute and 30 seconds of the 2 minutes and 32 seconds that Kipchoge knocked off Kimetto's world record.

We ran four simulations:
The first case is a worst-case scenario - an undrafted solo runner - while the fourth case simulates the actual conditions of the Breaking 2 attempt, in which our virtual Kipchoge is following the pace car (and timing board) whilst surrounded by a team of athletes in delta formation.

The simulations comprise four million computational cells for the solo runner, 8.5 million for the pack formation, 22.5 million for the car and virtual Kipchoge and 24 million for the rest, and in the wake of, the car and runners. The kw-SST turbulence model was used (for those of you wondering) and we also verified the simulations using a k-ϵ Realizable model, which was within 2 percent agreement for the baseline and final cases;
y+ was <20. For simplification, each of the runners is assumed to be a static mannequin frozen in a single running pose (we do not model the running movement of the arms and legs, although we have previously demonstrated that the average drag on a pedaling cyclist is well predicted using a static model).

The plots in figure 2 show the velocity field around our virtual Kipchoge in each

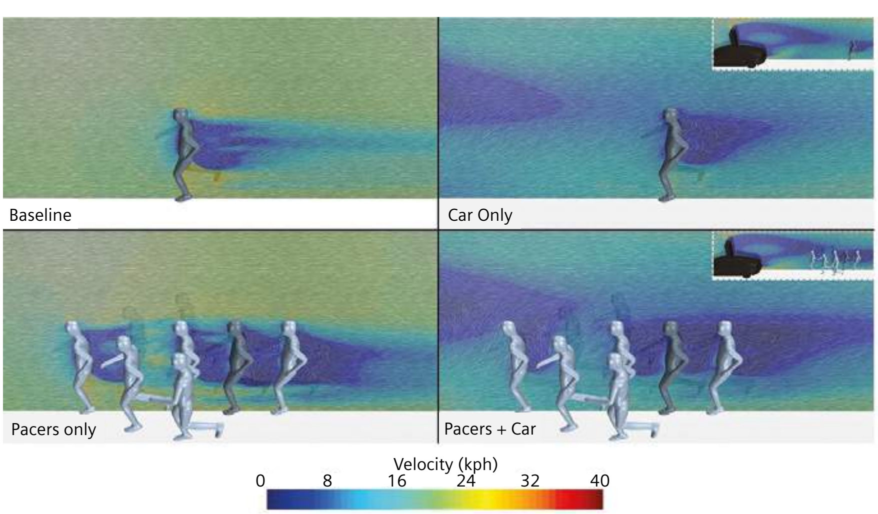

Figure 2: Velocity field around virtual Kipchoge in each of the four scenarios

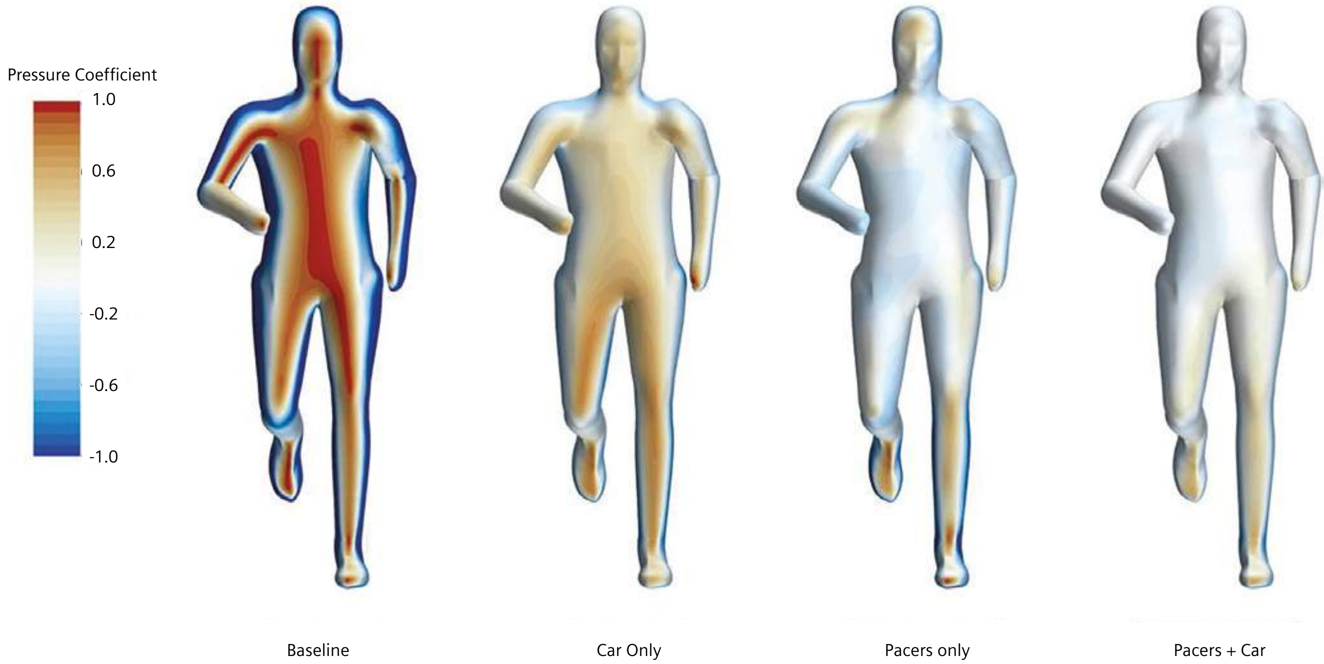

Figure 3: Drag force acting upon Kipchoge in each of the four scenarios

of the four scenarios. The dark blue areas show areas in which the air velocity is less than five miles per hour (mph). In both the cases with pacers, Kipchoge is running into a five mph "wind" despite traveling at almost 13.1mph.

From the plots of velocity, you can see that the pacers do a great job of shielding Kipchoge from the wind. Our calculations suggest that the only real benefit of the car and timing combination is in preventing Kipchoge catching the wind in his face. The wake behind the timing board tends to skew upwards more because of the high-speed flow beneath the car (which has a flat floor) expanding as it exits the diffuser and the chasing pack has a higher pressure zone ahead of it, which then diverts the flow around it.

More usefully, we can integrate the pressure acting over the surface of our virtual Kipchoge, and calculate the drag force acting upon him in each of the four scenarios. (see figure 3)

It is easier to interpret these results if we consider the "energy required to overcome drag", which is the force acting on our Kipchoge, multiplied by his forward velocity (just under 13.1 mph). The energy that Kipchoge saves in not having to overcome aerodynamic drag should be available for him to transfer to the road surface, and in principle run faster. See figure 4.

Given that Kipchoge is capable of running at roughly about 300 watts (W), the difference between undrafted and fully drafted scenarios is around 31W, meaning that he can probably devote an extra 10 percent of his effort to running faster in the latter case.

Perhaps surprisingly, most of that saving is generated by the close delta formation of pacers around Kipchoge which generates a 28W saving even without the car, which only adds another 3W to the total.

Because power output varies with the cube of velocity it is possible to estimate the amount of time saved in comparison with the undrafted runner. Our calculations suggest that the pacers saved Kipchoge about 4 minutes and 9 seconds compared with a solo runner, and the pacers and car combination saved him about 4 minutes and 35 seconds.

The undrafted case is an absolute worst-case scenario (other than perhaps running into a headwind). Elite marathon runners do not set world records while running alone, typically

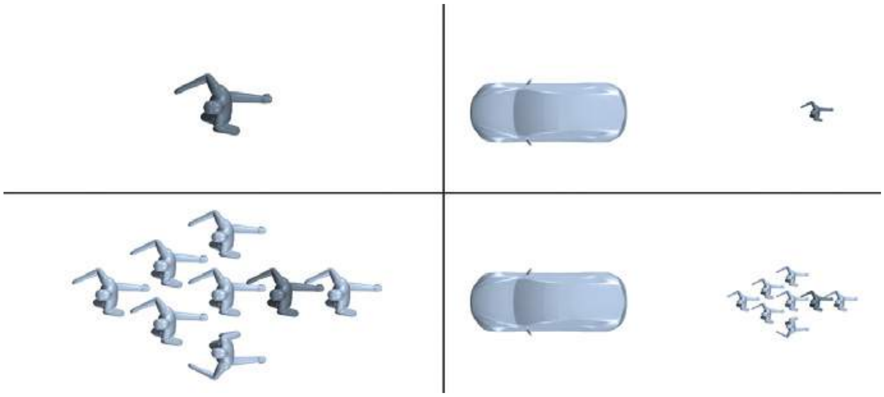

Figure 4: Aerodynamic drag calculation

burying themselves in a pack of runners to well beyond that halfway point. Kipchoge didn't hit the front until about 21 miles into his world record run in Berlin in 2017. We don't think that it is unreasonable to assume that Kipchoge would run several minutes slower if they were forced to run solo for 26.2 miles. The fastest female marathon runner, Paula Radcliffe, ran almost two minutes faster when surrounded by male runners (who were presumably drafting her) than when front running in a female-only race, a world record that lasted for 16 years.

INEOS 1:59

INEOS 1:59 attempt employed similar, but with refined tactics designed to enable Kipchoge to run at least 26 seconds faster and to become the first athlete to break the 2-hour barrier.

The first big change was the course choice. Replacing the twists and turns of a motor racing course with laps a 2.7-mile long boulevard in the center of Vienna. Unlike the previous attempt, spectators were encouraged to line the sides of the road, offering extra encouragement to all of the runners.

A similar pace car was used to project laser guidelines for the runners (showing both the speed at which they needed to run and how they needed to align themselves for optimum drafting). Unlike in the previous attempt, the prominent (but largely ineffective) giant clock was not present on top of the vehicle.

Another change was the evolution of shoe technology. Instead of the single spring shoes that he had used during the previous attempt and during his legitimate world record run, this time Kipchoge wore Nike Vaporfly Next shoes that included three spring plates and two cushioning air pockets, all of which were claimed to increase his running efficiency, and thus reduce energy expenditure, by more than 4 percent.

However, the biggest change was in the pacing formation, and how the pacers were deployed. Gone was the delta formation of the previous attempt, replaced by a new "inverted V" formation, which at first sight seemed slightly counter-intuitive from a pure aerodynamics point of view.

Delta formations occur naturally whenever the aim is to minimize the drag forces acting on a body or a group of objects. Think of the shape of the peloton in a cycle race, or the formation of a skein of migrating geese. However, the aim here is different; unlike in a conventional race, the pacers in these attempts are expendable, being swapped in and out of the pacing formation as they become exhausted or their performance begins to drop. So rather than minimizing the drag of the whole pack, as in the previous attempt, this formation seemed to be specifically designed to minimize the drag on Kipchoge alone, at the expense of greater energy expenditure of the pacing group. Two runners were placed behind Kipchoge to reduce his base pressure and therefore aerodynamic drag further.

Whereas the original Breaking 2 attempt used 30 elite pacers, the INEOS 1:59 attempt used 41 pacers, demonstrating anecdotally that the load on each pacer was increased during the second

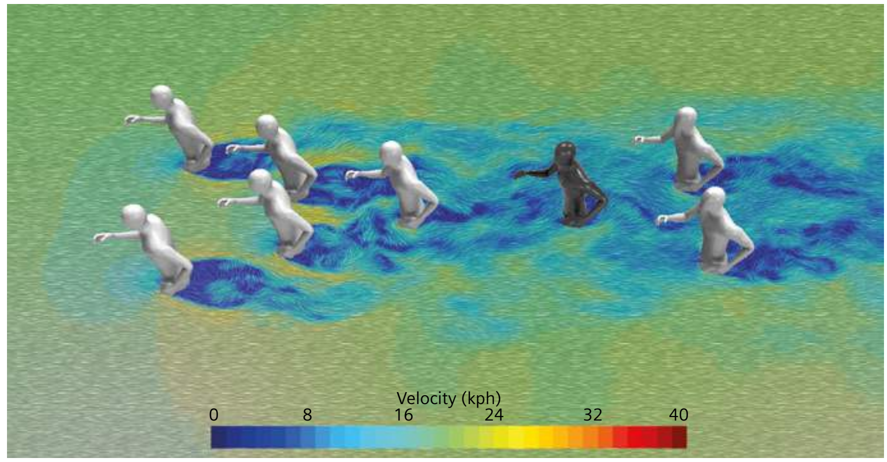

Figure 5: Velocity field around the runners in an "inverted V formation" used in the INEOS 1:59 attempt.

attempt. The profile of the pacers was also different this time, as the INEOS team employed more 1500, 5000, and 10,000 meter (m) specialists who are capable of running at a faster speed for shorter stints than the marathon and half-marathon specialists used previously.

The CFD results suggest that new inverted V formation did indeed cause a further reduction of drag, by about three percent over the previously employed delta formation. This is equivalent to about a further one Watt in effort required to overcome drag and worth about a ten second saving over the course of the marathon distance. A small amount, but in the world of "marginal gains" perhaps a significant one.

Limitations

The drafting cases, as simulated here, are absolutely the best-case scenario (excluding a strong tailwind). As organized as the pacing teams were, they weren't the perfect static obstacles that this simulation assumes and there were times at which the runners were not running in perfect formation. The natural running movements of the athletes would probably also expose Kipchoge to additional drag.

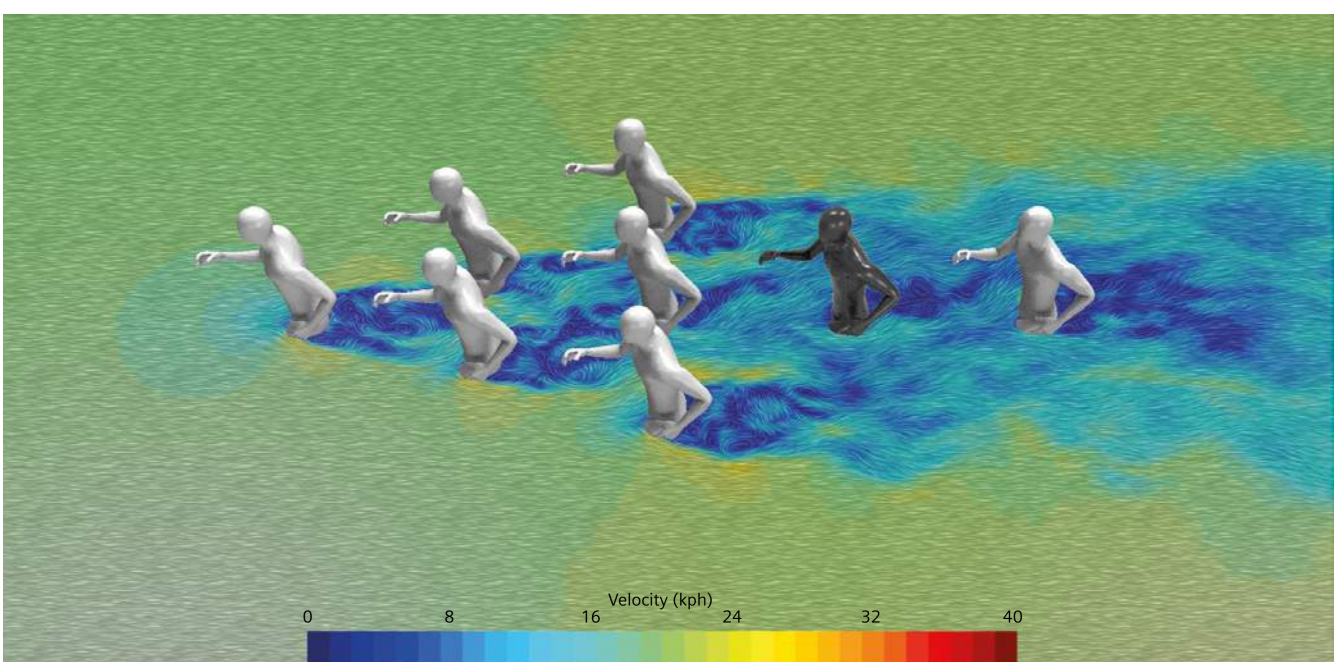

Figure 6: Velocity field around the runners in the "Delta formation" used in the Breaking 2 attempt.

There will be other limiting factors that we are not considering. Kipchoge's ability to dissipate heat will probably have been compromised as a result of the drafting - especially when considering that any cooling air that reached him will have traveled past other hot runners - in fact, he was sometimes seen moving to the wing of the formation, perhaps to cool down. This might be a second or third-order effect, but worth maybe considering for an athlete competing at the absolute limits of human performance.

Also, the mannequin isn't a perfect representation of Kipchoge, and it looks like our "virtual Kipchoge" could usefully use some tailored nutrition to lose a few pounds of virtual fat.

Conclusions

Kipchoge is absolutely the best marathon runner in the world, probably the greatest of all time. Whatever aids he had, legitimate or otherwise, this was still one of the greatest feats of endurance running in history.

Our simulations suggest that the influence of pacers, reduced the aerodynamic drag experienced by Kipchoge by a maximum of about 83 percent, saving him over 30 Watts, (about 10 percent of his overall effort level), compared with a completely solitary runner at the same speed. This reduction in drag could be worth as much as 4.5 minutes, compared with an undrafted runner at the same speed. However, since his legitimate world record was run in partially drafted conditions, and our simulations are somewhat idealized, it is likely that the actual time saved was significantly less than 4.5 minutes, compared with a regular big-city marathon.

As impressive as this 1:59:40 was, aerodynamic factors plus any contribution from shoe technology mean that this effort was somewhat less impressive as an athletic feat than his genuine world record run of 2:01:39. However, it would be churlish not celebrate both the achievement and the inspiration that Kipchoge will have provided to generations of athletes, including in beating my own marathon personal best of 2 hours 182 minutes and 17 seconds.

We are doing further design exploration simulations, in which we examine all possible pacing formations to determine which is the most effective. Keep an eye on the Simcenter blog to see those results.

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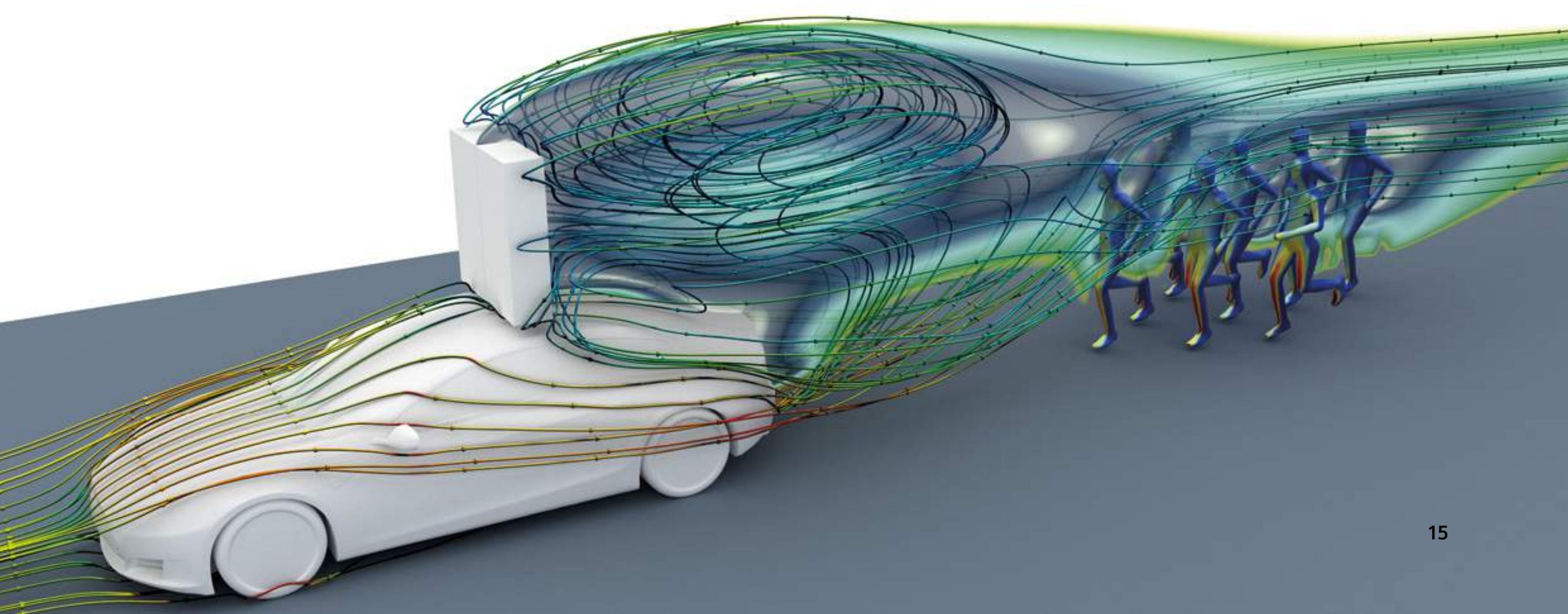
[3] The Science of Sport: The pursuit of the sub-2 marathon: Where to next? www.sportsscientists.com/2017/05/pursuit-sub-2-marathon-next/ ■



Vyaire Medical: Breathing new life into respiratory care

Leveraging CFD in the development of differentiated respiratory and anesthesia care devices

Stephen Ferguson talks with Dr. Christopher Varga, Senior Fellow at Vyaire Medical

Most of us take breathing for granted, taking around 17,000 to 23,000 breaths per day, mostly without any conscious effort. However, for many reasons, breathing can present a significant challenge to the elderly and infirm. For premature babies, with tiny under-developed lungs, minimizing the effort of breathing is critical, as every calorie of wasted energy expenditure negatively impacts clinical outcomes. Even for elite athletes, with highly developed cardiovascular systems, the efficiency of one's respiratory system is the most critical factor in determining success in competition.

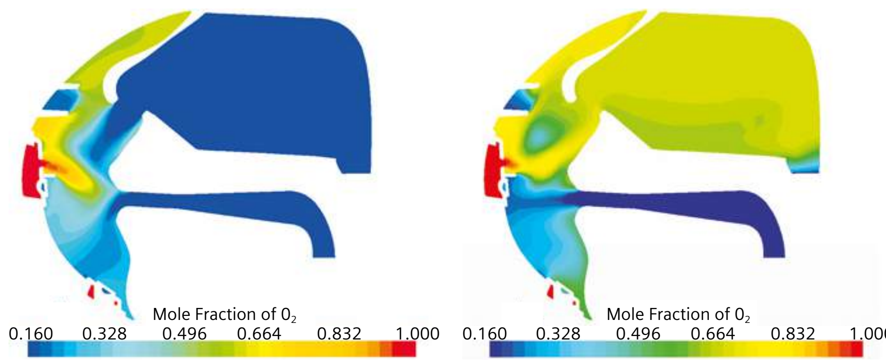


Figure 2: Simcenter STAR-CCM+ simulation showing oxygen delivery for a light mouth breather (left) and a heavy breather with mouth and nose (right)

Vyaire Medical is a global market leader in healthcare technology, providing a comprehensive line of respiratory products serving the smallest neonate to the largest adult patient. The story of Vyaire began in the 1950s on two different continents, due to the tireless efforts and dedication of two pioneering medical innovators. In the U.S., Forrest Bird invented and refined the mechanical ventilator. Nearly concurrently in Germany, Erich Jaeger developed what would become the first complete laboratory for pulmonary function testing and diagnostics. Today, Vyaire manufactures and markets more than 27,000 unique products for the diagnosis, treatment, and monitoring of respiratory conditions in every stage of life.

The "every stage of life" commitment presents a considerable engineering challenge. Not only do patients come in a variety of shapes and sizes (morphologies), but they also breathe in a variety of ways: some people are "mouth breathers," some are "nose breathers," most of us breathe using a combination of both. Also, each patient has a unique breathing profile that depends on their lung function and structure. As such, simulations used to predict the performance of respiratory devices must account for these variables to ensure and maximize their effectiveness across the broad range of patient characteristics.

The man tasked with creating the robust simulation process that allows Vyaire to deliver on this commitment is Senior Director of research and development Dr. Christopher Varga: "Historically we were forced to use more simplified models, for example in the development of a respiratory mask, we would have used a simplified head model on our computational fluid dynamics (CFD) simulations, with idealized breathing holes for the nose and the mouth," explained Dr. Varga. "Although we were

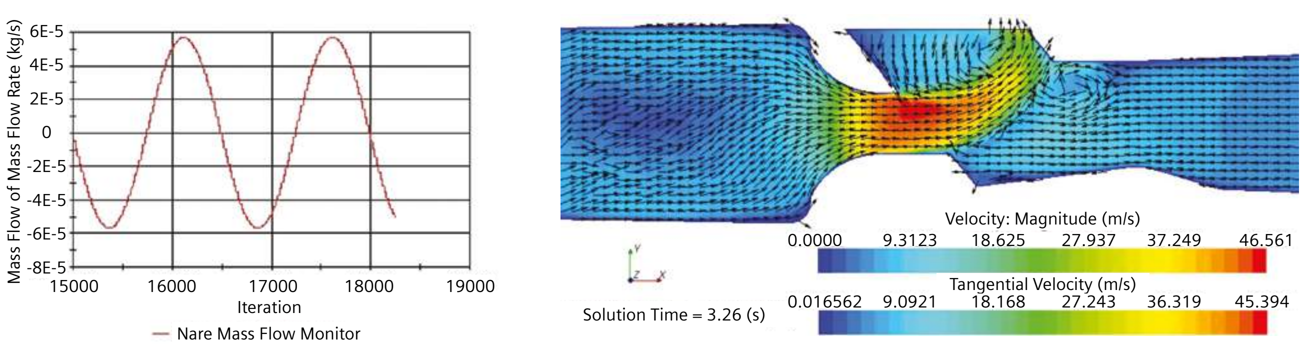


Figure 3: CFD simulation was used to design the best-in-class infant nasal CPAP system with the lowest work of breathing

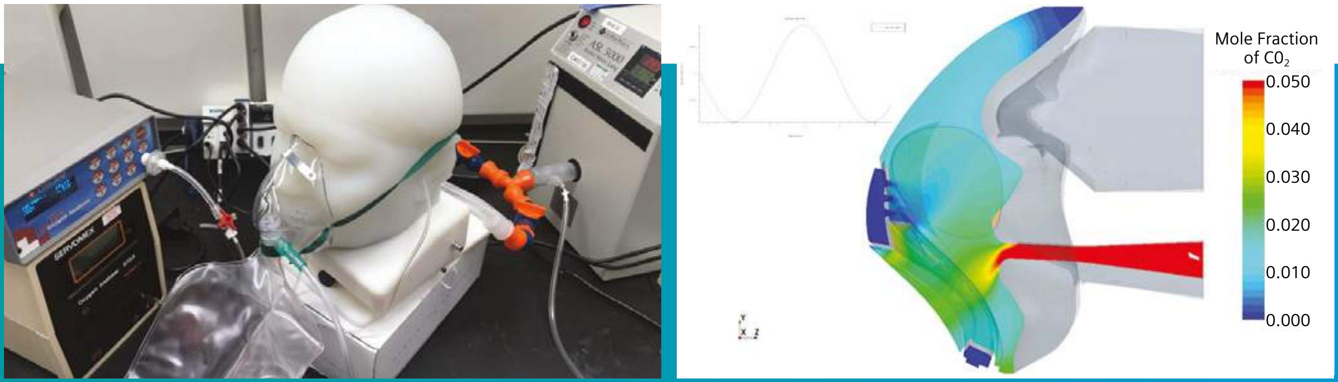


Figure 1: Vyaire respiratory mask on a real patient morphology (left) and Simcenter STAR-CCM+ simulation on the same representative patient geometry (right)

able to extract meaningful engineering data from those types of simulations, they don't allow us to simulate all of our use cases realistically."

For this reason, Varga set about improving the simulation process by gradually introducing more patient-specific data into CFD simulations, using Simcenter STAR-CCM+.

"We are now using scans of real human heads that represent the morphologies of actual patient features. When it comes to respiratory simulations, we incorporate lung structure and volume using a variety of breathing profiles," said Varga. "We are starting to build a library of patient morphologies, which already consists of representative patient geometries for all of the patient populations: adult, pediatric, and infant."

In other words, the simulations account for "every stage of life." Vyaire's commitment to realistic simulation doesn't stop there, though; within those broad patient categories, Varga and his team are developing a complete library of patient morphologies and usage scenarios.

"For example, consider a patient who is sick or an elderly woman who has stiff lungs. We need to design devices that can be used for that patient as well as a more healthy patient, or perhaps even a highly tuned professional athlete with enormous lung capacity," explained Dr. Varga. "Within each patient category, we are starting to build that out, from average to bariatric head models, so that we can simulate the entire spectrum of clinical usage."

The ability to optimize the capability of a product across all it's possible usage scenarios means that simulation is becoming more and more pervasive in the development process for medical devices.

"Simulation has brought to light a unique exploratory power for medical device engineers and researchers to design and build better solutions much more efficiently," said Varga. "CFD already plays an important role in the front and the middle of our development cycle, and we expect increasingly to find a role in regulatory validation and verification. The power of simulation for medical device development has grown even greater with the capability to incorporate the patient into the simulation."

The payoff for investing in this detailed simulation approach is significant.

"Early in the development cycle, we extensively use CFD to achieve our feasibility goals through simulation rather than using time-consuming and expensive physical prototypes", concluded Dr. Varga. "Having the capability to develop our products using Simcenter STAR-CCM+ allows us to significantly reduce development times and results in higher quality products and better patient outcomes." ■

Figure 4: Samples of representative patient geometries scanned to generate simulations on patient-specific geometries

Hyundai Motor Company

Global automotive OEM adopts Siemens Digital Industries Software solutions to minimize transmission gear noise

"Simcenter 3D Motion Drivetrain is a useful tool that enables us to model the gear train with different levels of fidelity depending on our analysis requirements."

Horim Yang
Senior Research Engineer
Hyundai Motor Company

Simcenter 3D helps Hyundai reduce gear whine in drivetrains

Simulating transmission behavior

Engines, tires and transmissions can be major sources of noise, and the noises and vibrations of the transmissions are a special focus. Especially for electric vehicles, in which conventional engines are replaced with electric motors, transmission noise/vibration become more prominent. Therefore, minimizing the transmission noise and vibration is a key engineering activity. Driving a vehicle should be a smooth, quiet and enjoyable experience. Drivers should be able to escape the noise of the hustle and bustle of big-city distractions in the comfort of their modes of transportation.

With the first car coming out of South Korea in 1975, Hyundai Motor Company has now been producing cars for over 40 years. Selling vehicles all throughout the world requires constant emphasis on design and engineering to produce the quality Hyundai is known for.

Utilizing multiple tools

Typically, simulating transmission behavior has been a tedious and error-prone process, requiring multiple simulation tools and long lead times. A key challenge in designing a transmission model that can be used to assess noise or durability is the need to correctly represent not just the overall gear geometry and layout but also the microgeometry of the gear teeth in order to fully capture the nonlinear dynamics. As such, modeling, parameterization and iterations to build a complex model can take days of effort for an experienced engineer.

Another important factor for Hyundai was narrowing down the processes and tools required to perform the tests it wanted to run. "From our experience using similar software tools, we found that one of the most common issues was the time required to create a complex transmission multibody model," says Horim Yang, senior research engineer at Hyundai Motor Company. "It was very time-consuming. Other packages lack modules to complete a seamless full-scale analysis on a transmission. Sometimes, we had to use multiple software tools together. This was a rather cumbersome workflow. We were looking for a software tool, ideally a multibody software, that can be used with finite element analysis to investigate and solve full vehicle and other NVH issues."

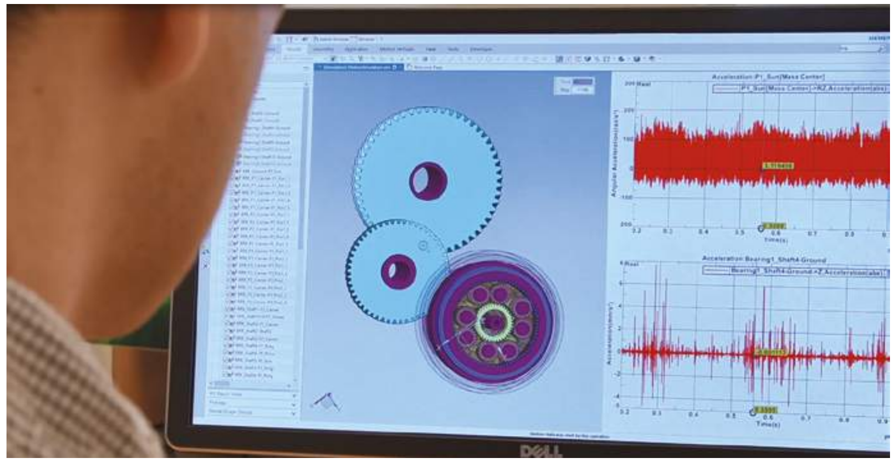
Hyundai turned to Siemens Digital Industries Software for a solution, selecting Simcenter™ 3D™ Motion Drivetrain and Simcenter 3D Acoustics software. “We had been using different multibody simulation tools for 1D and 3D simulation, but it was difficult to find an adequate software tool with a properly detailed gear dynamic simulation module,” Yang continues. “The Simcenter 3D Motion Drivetrain transmission builder can do a good job for the analysis that we require.”

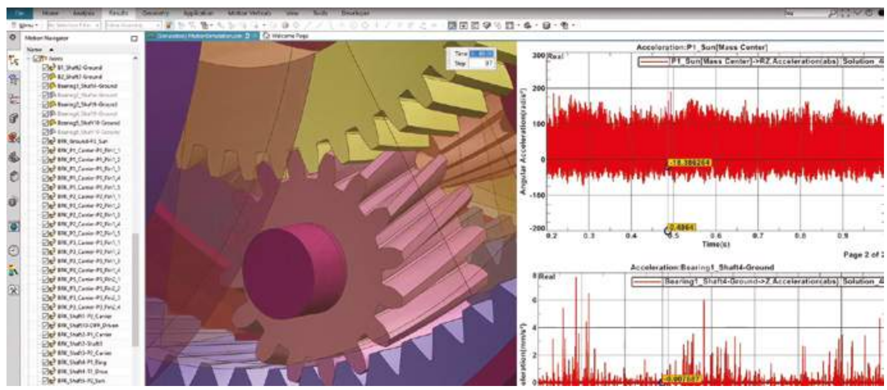
Eliminating extra steps
With the Siemens solution, Hyundai engineers now apply the latest simulation techniques to determine the best possible components for their vehicles. The ability to run digital simulations greatly reduces the need for physical prototypes early on in product development. This, in turn, means a reduction in the overall cost of the project.

“The tool can be used during the initial design stage to examine how the gear train design parameters influence the system-level dynamic behavior in a drivetrain,” Yang explains. “It can be used to confirm the dynamic performance with a detailed gear train noise and vibration analysis in the final design stage.”

Simcenter 3D Motion Drivetrain and Simcenter 3D Acoustics help automate the creation and simulation of transmission motion models within a single, integrated simulation environment. Hyundai’s goal has been to utilize Simcenter tools to greatly reduce noise, vibration and harshness (NVH) in large cars and SUVs.

Simcenter 3D Motion Drivetrain can help reduce transmission simulation efforts by 80 percent, and is a vertical application that enables engineers to easily define and simulate complex transmission systems based on industry standards. Hyundai engineers can simply enter basic parameters to define the configuration of a transmission system. From these parameters Simcenter 3D automatically creates the full 3D transmission model, including geometry. Hyundai engineers can then set gear contact parameters and operating conditions for the transmission, and the entire model is ready to solve in just minutes instead of hours or days.





Solving complex engineering issues
Additionally, transmission models can then be seamlessly integrated into Simcenter 3D Acoustics to perform gear whine analyses. According to Yang, “Simcenter 3D Motion Drivetrain is a useful tool that enables us to model the gear train with different levels of fidelity depending on our analysis requirements.”

“Thanks to our Simcenter Engineering and Consulting services project with Siemens Digital Industries Software, we hope to establish an efficient workflow to apply multibody simulation results to NVH and durability analysis and find the right software tools that fit our requirements,” says Yang.

It was important for Hyundai to find a solution that gave both the desired output and was easy to use. “From this perspective, the transmission builder software is well-suited for our engineering purposes,” says Yang. “It has a user-friendly interface.” ■

Not in my backyard! How annoying is wind turbine noise, really?

Although everybody is in favor of clean and green energy, when new wind turbine parks are built, nobody seems to want them in their backyard. Next to the visual pollution of the landscape, increased casualties among bird and bat populations, and the so-called shadow flicker effects, people also complain about wind turbine noise.

While some residents living close to wind farms find the “swoosh” sound of wind turbines pleasant to hear, others complain about the noise, from it being a simple annoyance to a sleeping disturbance, and even claim to have caused health problems. Wind turbine noise has therefore become a controversial topic, showing that every person perceives the sound generated by them differently.

But what are the facts?
Well, in reality, a wind turbine does not make that much noise at all! At 300 meters it is not louder than your average personal computer or home refrigerator. Of course, modern wind turbines get bigger and bigger, and their blade tips often reach speeds higher than 200 kilometers per hour (km/h), making more noise. However, overall sound levels still stay low.

Legislation also steps in to make sure noise limits are not exceeded: every type of wind turbine needs to undergo a noise certification test according to the IEC61400-11, resulting in a sound power curve for different operational wind speeds.

Once the wind farm is operational, there are environmental regulations that monitor the wind turbine noise levels around it and make sure they are not higher than the legally allowed limits. This often means that during the night, for instance, wind farms need to run sub-optimally to not exceed background noise levels.

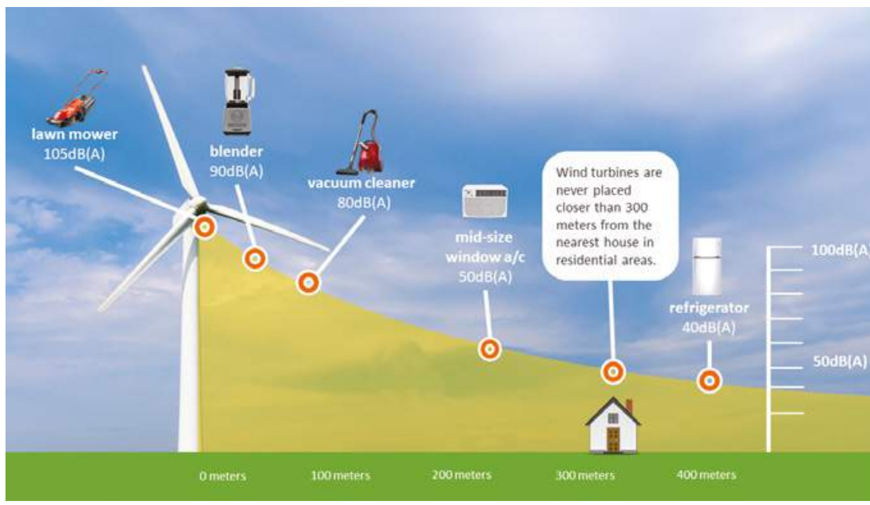


Figure 1: Wind turbine noise levels at different distances

So, what's the problem? Are all those complaints fake news?
Well, not exactly. Not only is the (averaged) sound pressure level is important, but so are transient noises and at the specific frequency content of the noise generated. The transient “swoosh” sound, made whenever a blade passes, can indeed be annoying to some people - especially during the night, when other environmental noise is less present.

Specific frequencies - such as tonal noises - although not very loud, can be annoying. The latest edition of the IEC61400-11 standard explicitly takes the analysis of those tonalities into consideration. During the night, one

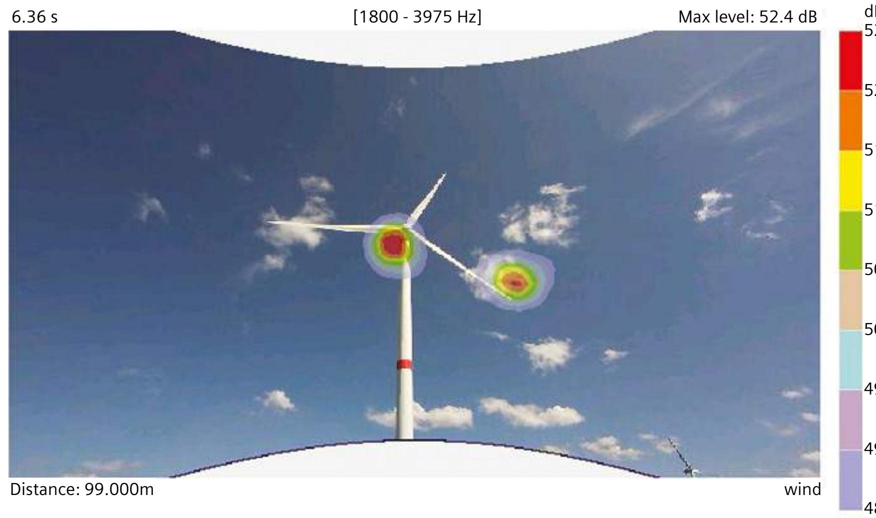


Figure 2: Simcenter Sound Camera - sound sources at nacelle and blade tip.

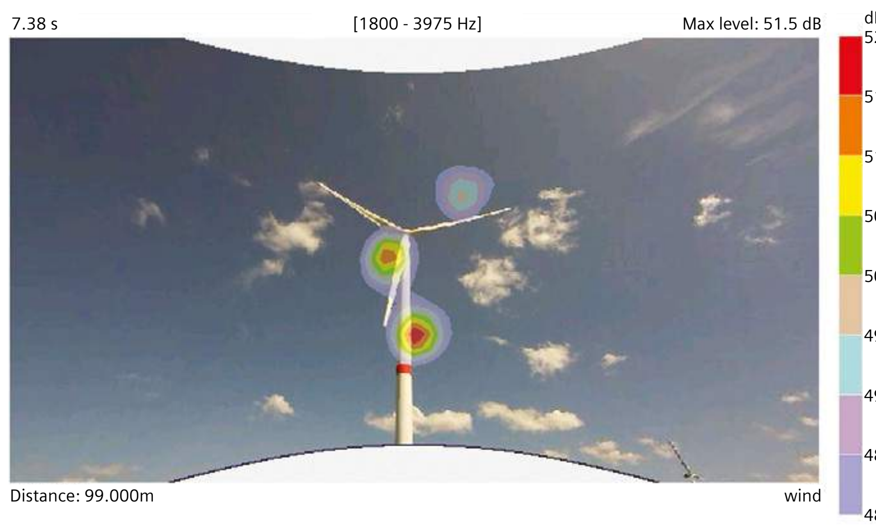


Figure 3: Simcenter Sound Camera – reflection and local turbulences sound sources.

might start focusing on those tones, which may indeed ruin one's sleep.

Tonal noises typically come from the gear set in the nacelle, from power electronics, motors for changing the pitch position of the blades or the yaw position of the nacelle, fans, etc. Understanding which parts of the wind turbine generate the transient noises, as well as possible specific frequencies, is a crucial step in addressing, or better yet, avoiding noise complaints.

How can we make sure these wind turbines aren't noisy?

In the engineering process of wind-turbine gearboxes, predictive simulations are used today to assess vibration levels. With Simcenter 3D Motion, multi-body simulations of entire transmission can be performed. The level of detail allows the prediction of noise and vibration by means of an acoustics simulation. This helps ensure minimal noise levels in the design phase, prior to building a prototype.

Still, with manufacturing tolerances, wear and tear, and installation effects, it can still be potentially hard to get to the root cause of noise. The Simcenter Sound Camera™ hardware is the ideal tool for this, as it is quick and easy to setup and delivers real-time visualization of the main sound sources and their frequencies. As an example, we simply put the Simcenter Sound Camera in the back of the car and drove to the wind farm of Sovet, a village in Belgium.

Although this measurement was done from an upwind position, the results clearly indicate the main sound sources as being:

- From the nacelle itself: both the noise from the gearbox, as well as the noise generated by the yaw system, make the wind turbine rotate when the wind direction changes,
- From the wind turbine blade: the tip creates the highest noise when it moves with the highest speed, and most noise is generated during the downward movement of the blade, and
- An additional source can be seen every time a blade passes the tower, due to reflection and local turbulences.

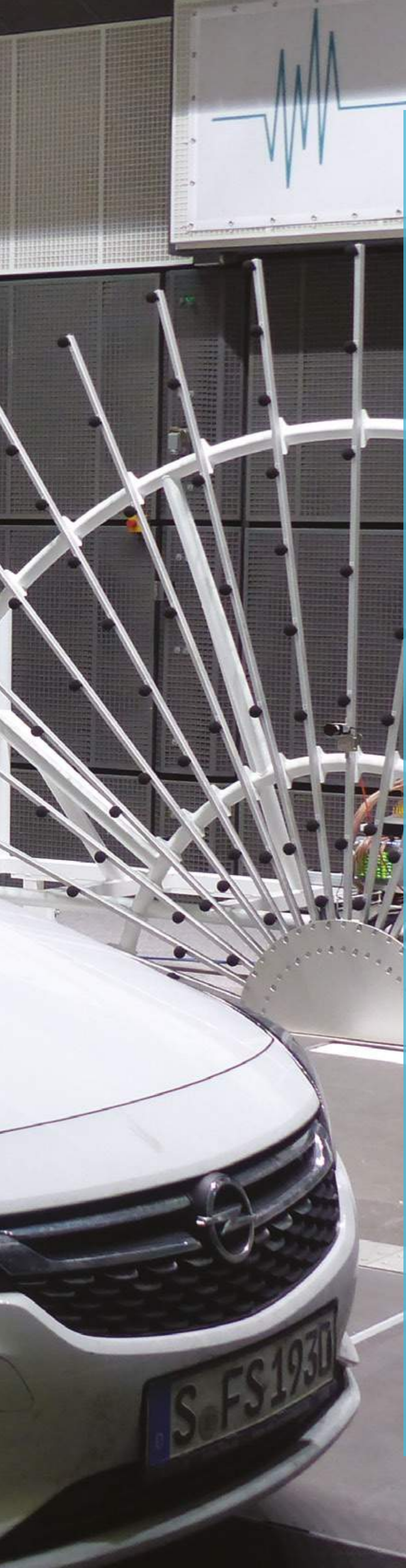
Often, for more detailed analyses, bigger customized ground arrays are used, and tests are done on scale models in aero-acoustic wind tunnels. However, thanks to the Simcenter Sound Camera, the initial analysis and interpretation of results is done in a much more efficient and effective way. With the Simcenter solution, one can compare different blade profiles by adding extensions to the trailing edge of the blades to investigate how it changes the emitted noise. By zooming in on specific frequencies, it is easier to identify the origin of the tonal noises and to determine if they come from the gearset, ventilators, power electronics, or any other source. This allows for last-minute changes before performing the formal IEC61400-11 certification.

In the end, wind turbines are here to stay and to make the world a little bit greener. They are cost-effective, sustainable, and a clean fuel source, among other benefits. ■

Figure 4: Test setup with Simcenter Sound Camera.

FKFS

FKFS achieves a winning difference for its aeroacoustic wind tunnel from Siemens Simcenter



FKFS offers highly efficient aeroacoustic wind tunnel testing and simulation services resulting in immediate vehicle advancements

FKFS: An important testing facility with a long history

The Research Institute of Automotive Engineering and Vehicle Engines Stuttgart (FKFS) is a well-established research institute providing testing, simulation and consulting services for the automotive industry. The scope of services comprises three parts: automotive engineering, powertrain and mechatronics. With extensive experience and almost 90 years of history in physical testing and simulation, FKFS has established a wide range of simulation and testing capabilities to deal with more or less all parts of a vehicle for different development stages. Following standardized ISO-certified procedures, FKFS today offers, among others, services of four wind tunnels: full-scale aeroacoustics, model scale, thermal and a digital wind tunnel. Some of the testing facilities, such as a mechatronic driving simulator with two-dimensional sledge and hexapod, is the largest in Europe.

The objective of the aeroacoustic wind tunnel is to understand how the vehicle design shapes the wind noise perceived in the cabin. To achieve the required engineering insights, the vehicle is positioned in the full-scale aeroacoustic wind tunnel at different flow speeds and under different yaw angles while measuring the exterior sound pressure radiated by the vehicle surface. Together with the interior acoustic measurements, these tests unveil the acoustic leaks and points of improvement for attaining driver comfort.

Automotive manufacturers understand that the vehicle noise, vibration and harshness (NVH) performance defines customers' perceptions and has a direct impact on the purchase decision. For this reason, a significant part of the vehicle development budget is allocated to acoustic testing to master the final NVH performance.

Advancing aeroacoustic vehicle development

To counter increasing competition in the world, where the number of aeroacoustic wind tunnels increased in past years, FKFS decided to upgrade and extend its aeroacoustic testing capabilities and invest in the latest and unique technology. "We are obligated to keep up with the competition, and the key is continuous innovation. Our customers had strong arguments that encouraged us to make this step," says Dr. Reinhard Blumrich, head of the Vehicle Acoustics and Vibration Department at FKFS.

In 2019, FKFS replaced the existing array-based acoustic mirror with the latest aeroacoustic testing technology. "For aeroacoustics, it is still difficult to rely only on simulation," explains Dr. Blumrich. "This kind of simulation is very complex and requires extensive time investments."

The new aeroacoustic wind tunnel testing system, deployed by Siemens Simcenter™ experts, consists of top and side microphone arrays including more than 300 microphones for the exterior sound pressure measurements as well as interior microphone arrays. This hardware is seamlessly connected with Simcenter™ Testlab™ software. "Now we can measure in one shot external and internal noise and correlate the results to see the coherence. Of course, this is much faster than before," says Dr. Blumrich.

Next-generation aeroacoustic wind tunnel

Unlike the previous generation of the testing equipment, which mapped the sound pressure on the vehicle locally, the new top and side microphone arrays provide the 3D representation of the sound field of the entire vehicle in one measurement. "In 99 percent of the cases we investigate the final interior

> *"It was impressive. Despite the short deadline, Siemens managed to deploy everything in time."*
>
> Dr. Reinhard Blumrich
> Head of the Vehicle Acoustics and Vibration Department
> FKFS

noise," explains Dr. Blumrich. "On one hand, we measure the external noise, where the noise is generated. And on the other hand, we measure the interior noise with the internal array, artificial head and microphones to have the connection between what happens outside and how it is perceived inside. And this is one of the main benefits of the Siemens Simcenter solution, that you can combine the exterior and interior measurements in a very sophisticated way."

This means that the vehicle design must be thought out and tested in detail, because each small design adaptation can have a significant impact on the final vehicle acoustic performance: consider parts like the A-pillar, side-view mirror, side windows, wipers and door handles.

"Our typical customers are vehicle producers, suppliers of, for example, sunroofs and windows," says Dr. Blumrich. "It is very common that finding the best design of the sealing system, A-pillar, side mirror and windshield requires a lot of investigation."

Significantly increased efficiency per session

The new technology applied in the wind tunnel opens new options for advancing the vehicle acoustic performance using "source-transfer-receiver" schematics. This approach separates the exterior sources from their transfer to the interior noise. This results in the ability to make informed decisions on how to best tackle the acoustic problem. For example, instead of adapting the door sealing design to avoid and block the final noise, this methodology identifies the possible adaptations of the noise source, such as changing the design of the side view mirror or wipers to avoid the noise generation. This approach provides FKFS and their customers with more ways to optimize the final acoustic performance.

In general, using the latest Simcenter wind tunnel testing technology, results that are obtained after a week of computational fluid dynamics (CFD) calculations can be achieved in a few minutes in the wind tunnel. The goal of this technology is to use advanced acoustic arrays to determine in real time

the aeroacoustic pressure inside and outside of the vehicle.

The test engineers usually begin by comparing different wind speeds and yaw angles (angles between flow and vehicle) and then proceed with design modifications to the vehicle. They can easily change different component variants and immediately compare the acoustic impact. The same applies to the interior parts like sealing systems at the front door and sealing around the entire car.

With the Simcenter wind tunnel solutions, FKFS engineers perform the measurements and access augmented and higher-quality information that enables customers to immediately evaluate the real-time results and interact. This was not possible in a short time frame with the previous approach, because of the limited performance, which prevented immediate vehicle adaptation. The new Siemens technology enables the development teams to make correct decisions during the wind tunnel testing campaign. “During a testing session, the client is typically together with our engineers in the control room,” says Dr. Blumrich. “Our engineers carry out the test, and the client can access the data immediately on a post-processing computer. The customers either follow their predefined testing schedule and analyze the data later, or they immediately proceed with some vehicle adaptation, like changing the antenna. It’s a very close cooperation between the client and our engineers.”

Providing testing value to customers

With the new Siemens Simcenter aeroacoustic wind tunnel system, FKFS increased testing efficiency by roughly a factor of two to ten, depending on the testing project and its scale. “With the new wind tunnel system in place, our customers can obtain much more information and more details per testing session, even more than they expect,” explains Dr. Blumrich. The 3D representation of the sound field accelerates the collaboration with the client. “This brings a great service that enables the client to have a better look into the sound field in the car or on the exterior.”

"With the new wind tunnel system in place, our customers can obtain much more information and more detailed information per testing session, even more than they expect."

Dr. Reinhard Blumrich
Head of the Vehicle Acoustics and Vibration Department
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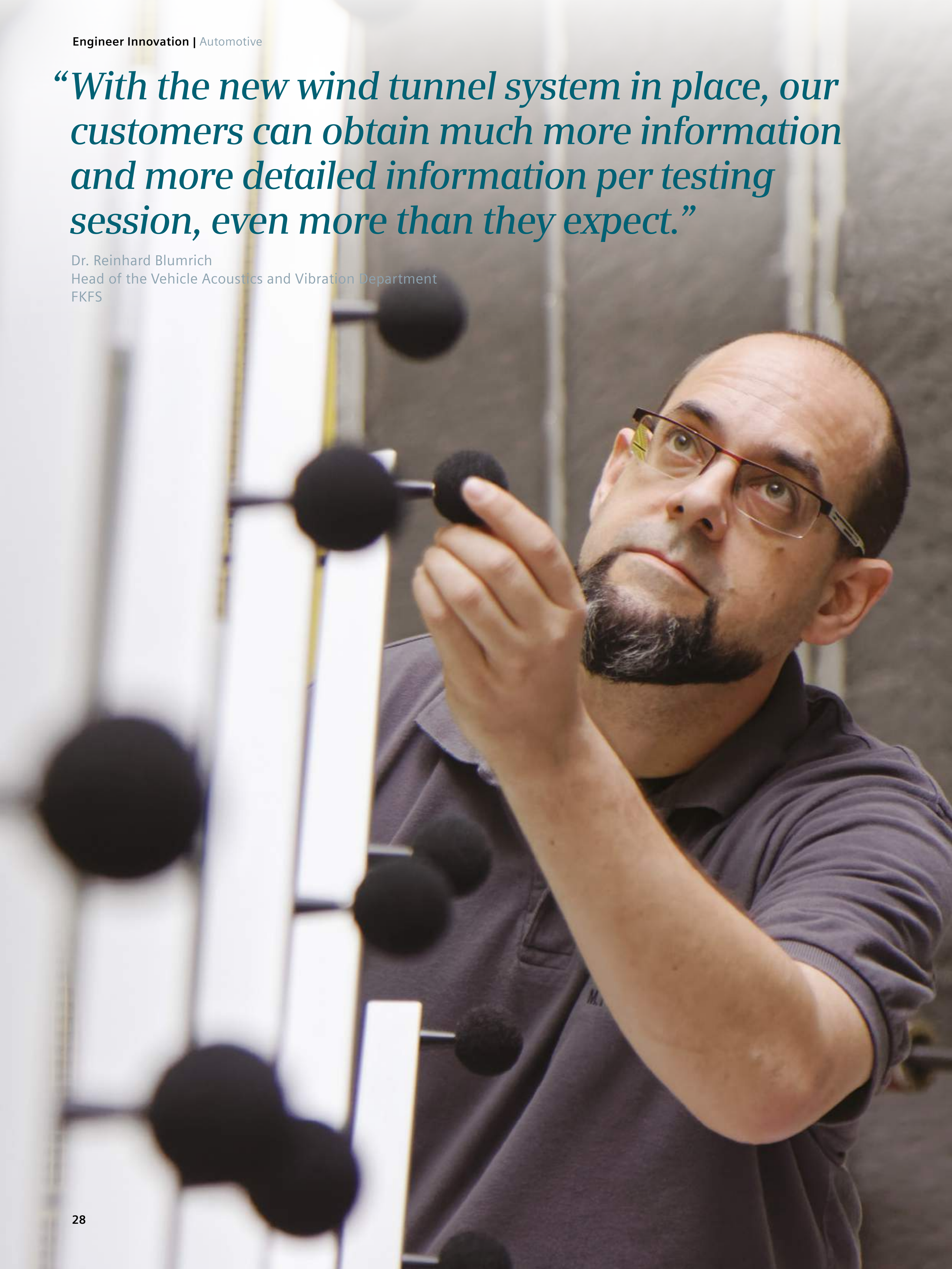


Automotive OEMs benefit from this technology by testing more vehicle variants with the same testing time investments. This upgrade brought new customers to FKFS, and the new testing equipment is extensively used and booked out for months. "There are even night shifts every other week to cover the demand," says Dr. Blumrich.

Aeroacoustic testing for electric vehicles

The decision to upgrade the aeroacoustic wind tunnel reflects the current trend of vehicle electrification. The absence of a loud combustion engine in hybrid and electrical vehicles, besides the tire-road noise, makes the aeroacoustic noise sources much more audible. "Because of the relative decrease of powertrain noise, the tire-road noise and aeroacoustic noise increases in relevance." Dr. Blumrich says. "And it increases the need for aeroacoustic measurements. If you remove the noise sources like combustion powertrain or side mirrors, human hearing will start to focus on other noise sources, which means that it becomes important to investigate and optimize other parts."

Fast project delivery and deeper collaboration

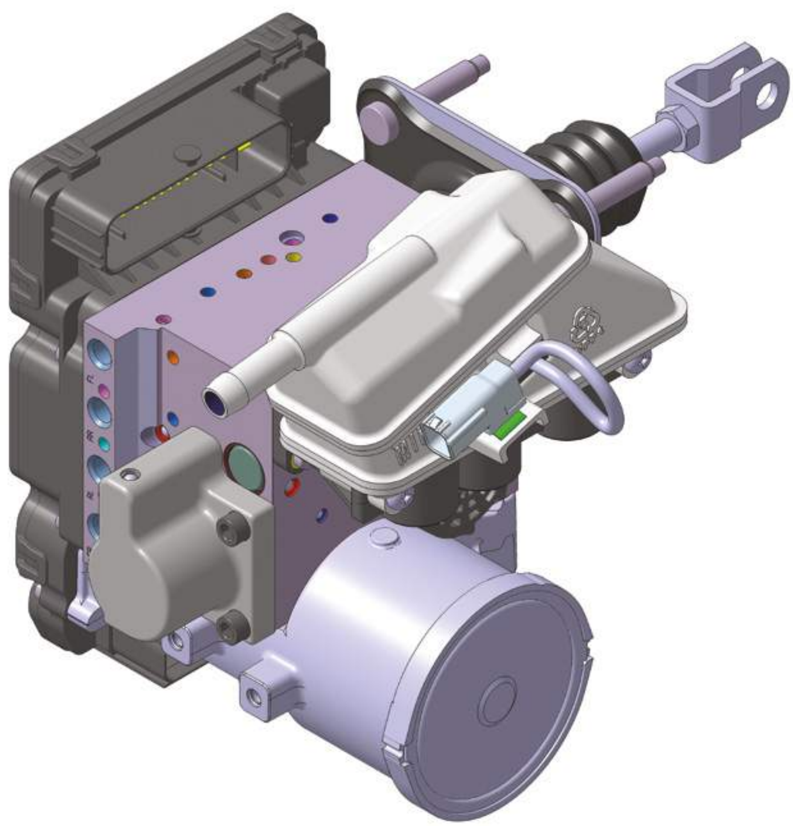
In general, extending an existing system with a new one doesn't only involve financial investments for the new system, but also the financial loss of missed projects during the reconstruction. This is an important supplier selection aspect, especially in testing institutions where every hour counts. Reviewing this project, Dr. Blumrich appreciates the project delivery and ways of cooperation. "It was impressive," Dr. Blumrich says. "Despite the short deadline, Siemens managed to deploy everything in time. In addition, Siemens offered additional cooperation projects for further enhancements of the system after the installation. We have a common understanding to start joint research projects in this respect. That was another reason why we selected Siemens as a partner."

FKFS has further developed its toolbox for optimizing the interior noise by focusing on the unsteady aeroacoustics, wheel rotation, and ground simulation for a correct underbody flow with respect to the upcoming trend of autonomous vehicles. ■

Interview

Saving lives with brake assistance systems

Spotlight on Mando: designing new electro-hydraulic braking systems with Simcenter Amesim



What are the current challenges for your company?
Erich Wachter: Automated driving and vehicle electrification have drastically changed all automotive systems. Braking systems have been no exception to this trend. Of course, emergency braking systems still need to fulfill their main role – to save lives, - but in the context of automated driving functions, they now require ever-faster pressure buildup. Moreover, unlike internal combustion engines, hybrid and electric vehicles often miss vacuum to actuate the brake booster. To provide braking support in emergency situations, additional components are needed. To address these challenges Mando has developed an innovative electro-hydraulic braking system – the integrated dynamic brake (IDB).

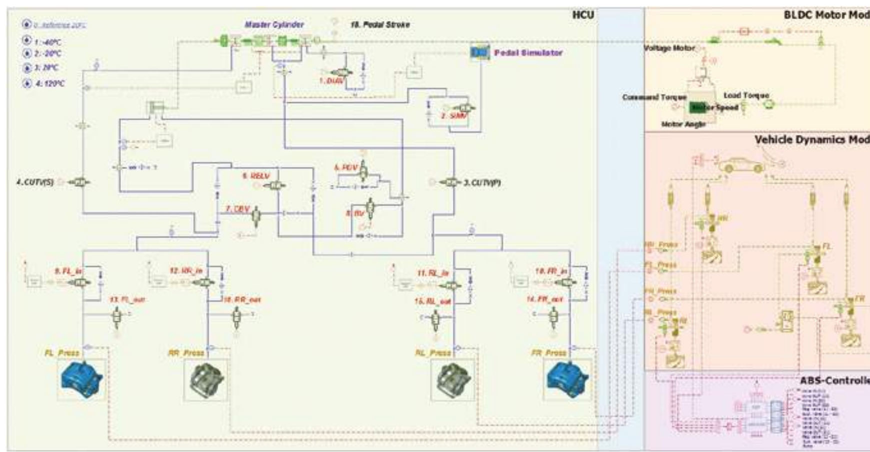
What's different about Mando's IDB?
Ti-Quanh Ngu: The key differentiator of our IDB is a greatly reduced braking distance. How do we achieve this? The braking impulse is transferred electronically from the brake pedal via a sensor to an actuator. This actuator generates the hydraulic braking pressure by means of a powerful brushless direct current (DC) motor, which moves the hydraulic pistons via a screw drive. The electronic control system takes over the driving dynamics control functions. A mechanical connection between the brake pedal and the hydraulic unit still exists – as a backup to ensure the braking function in case the vehicle's electrical/electronic systems fail. In contrast to conventional electronic stability program (ESP) systems (where the electro-motor only functions when the control system modulates the pressure), in electro-hydraulic braking systems, the electro-motor is activated for every braking maneuver and is, as a central component, responsible for the pressure buildup, and braking performance.

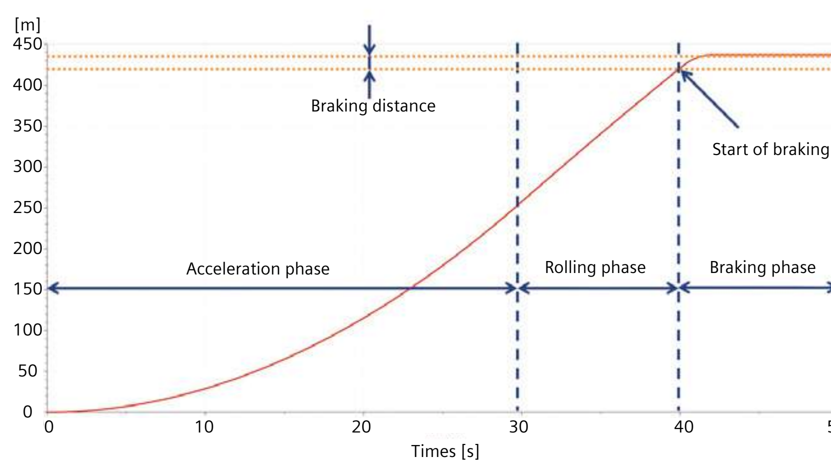
How did this innovative design impact your development processes?
Erich Wachter: Obviously, such innovative systems in charge of human security must be thoroughly tested before being released to the market. That increases the costs. To be faster and more efficient than our competitors while continuing to ensure security, we maximize the use of simulation, particularly the use of Simcenter Amesim.

What kind of analyses do you run with Simcenter Amesim?
Ti-Quanh Ngu: For the IDB, we used our Simcenter™ Amesim™ hydraulic model of the brake assistance system to find out how changes in the hydraulic circuit and variation of different parameters impact the overall braking system's performances (time-to-lock value, stopping distance...). By changing the performances of the electrical motor, as well as hydraulic properties, we can adapt the braking system to the vehicle configuration without running any physical tests. What is exciting about Simcenter Amesim is that every small change in the hydraulic circuit and its components can be captured by the software.

What do you appreciate the most in Simcenter Amesim?
Erich Wachter: You can use the same model from the initial concept, to system and component design, until vehicle integration; and it can be also exported into another software. We can easily create S-functions to couple our models with Simulink. Finally, we use our models to demonstrate to our customers that our products behave as expected once integrated into the vehicle. Simcenter Amesim enables us to run as many simulations as we need without damaging hardware, keeping our development costs under control.

How did Simcenter Amesim impact your day-to-day work?
Ti-Quanh Ngu: Simcenter Amesim has completely eliminated the need for dealing with mathematical formulas: we can rapidly get accurate results by simply using the validated components, and evaluate the performance of multiple IDB configurations under different operating conditions. We can even exceed challenging customer specifications: for instance, we have found out a design which reaches caliper pressure gradient of hundred bars within less than 150 milliseconds. ■





The space launch, a highly competitive market

By Sylvain Pluchart, Aerospace and defense business development manager, Simcenter system simulation

In 2018 a total of 114 orbital launches were performed globally, reaching the 100 launches mark for the first time since 1990. 2019 is shaping up to be of the same kind.

Underlying this trend is the ever-increasing number of payloads to launch. On top of that, new applications are emerging in the space economy, such as space tourism or mass deployment of small satellites to provide worldwide internet access.

In this context emerging actors from the private sector are driving the launch costs down thanks to a new way of doing business. One notable trend is the development of small launchers targeting lighter payloads and suitable for high launch cadence. Another focus of research is the reusability of some part. Since 2010 it has been estimated that launch cost decreased from 10 to 15 percent.

Engine performance holds the key to launcher success
A key enabler of these innovations is the engine performance. Modern rocket engines are designed to be shut down and restarted multiple times during the flight. The task is challenging for the designers because they must deal with unique constraints linked to propellant management, and thermal preconditioning of feed lines and engine components. For example, before an engine restarts, pumps are cooled down using the fuel onboard to avoid cavitation at start-up. This is done through a complex control sequences of valves and actuators.

Compared to older designs, the engine controller must be improved as it plays a major role in the engine capability to deal with the severe conditions related to multiple start-up and shut down.

Benefits of an engine transient simulation model
Fine-tuning the start/stop sequence usually requires many trials during ground testing. As an example, 3171 hot-fire tests were performed on the NASA's Space Shuttle engine. It represents more than 1,095,677 seconds of operation. This approach is costly and does not allow to easily extrapolate the engine operation in flight conditions. During tests the safety of the engine and the test equipment is a concern, especially at early stages when the physical knowledge of the engine behavior is not fully understood.

Transient simulation of models allows to frontload the analysis of the start/stop sequence and implement required design changes earlier in the development. They contribute to the cost and risk reduction of the engine development program by:

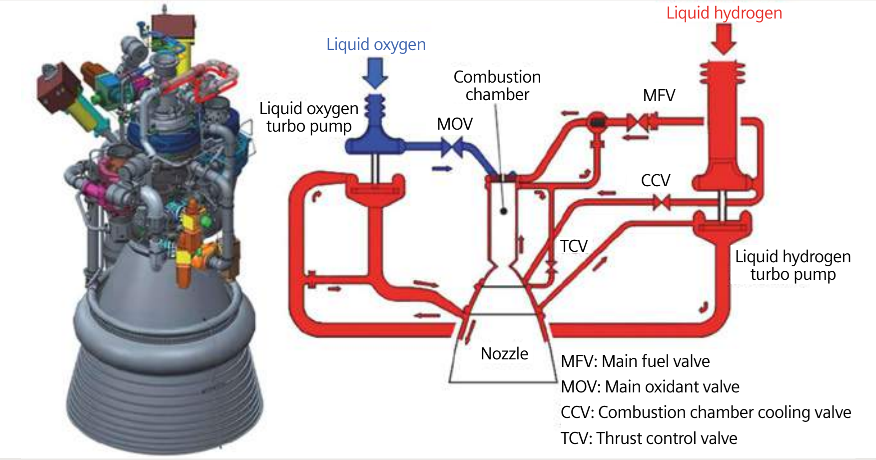
- Evaluating the design performance in a virtual environment,
- Simulating failure cases and predicting the operating redlines (tests safety), and
- Complementing the test results in preparation of the real flight conditions.

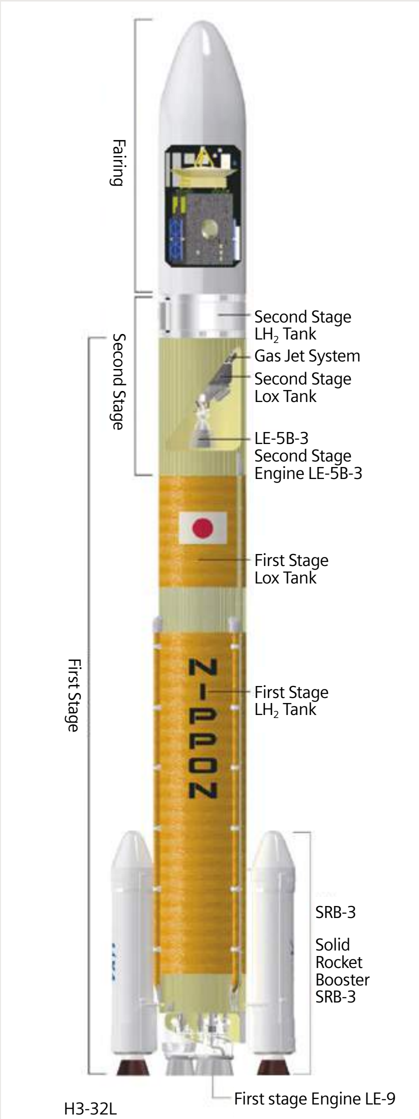
When coupled with a model of the controller, transient simulation can be used to support the development and the validation of control chains.

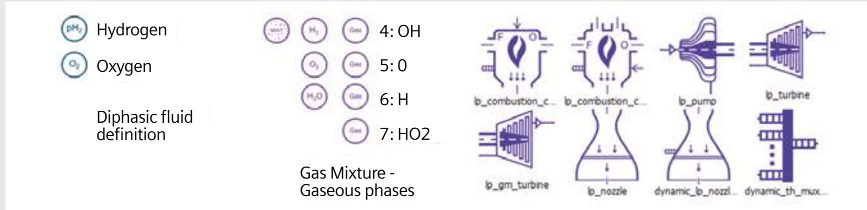
Mitsubishi Heavy Industries case study: the H3 as Japan's next flagship launch vehicle
The H3 launch vehicle development started in 2014 to "compete and survive in the global commercial market", as stated by Mitsubishi Heavy Industries Ltd. (MHI) in a technical review in December 2017. Like ArianeGroup's Ariane 6 or SpaceX's Falcon9, the design of the H3 launcher focuses on reducing both launch and operational costs, while keeping the high reliability of the current versions H-IIA/H-IIB.

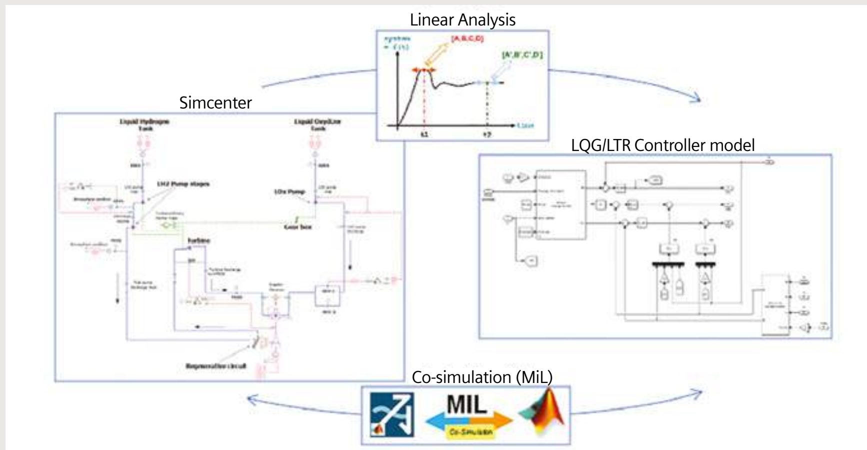
MHI is the primary contractor for the vehicle development, including the development of the engine system. The program is currently in a detailed design phase and progresses towards a first flight in 2020.

Second stage engine of the H3 launcher: LE-5B-2 transient simulation model
As the LE-5B-2 development started, two pain points were identified by MHI's engineers:









- One of the MHI's older engine design required one hundred tests and three years duration to fix the start/stop sequence, and
- As experienced workers leave the organization, they take with them accumulated knowledge and skills, making it difficult to maintain and upgrade legacy simulation tools.

Simcenter Amesim was selected to develop the transient simulation model of the LE-5B-2 engine. When using Simcenter Amesim the engineers benefit from the latest development of Simcenter Amesim liquid propulsion solution (and the associated libraries, Two-Phase flow and Gas Mixture).

Building engine models in the Simcenter Amesim environment ensures that simulation results will remain reusable and accessible to anyone in the design team.

The LE-5B-2 engine model results were compared with existing results, showing a good agreement with both the in-house simulation tool results and firing tests.

Modern control design for the first stage engine LE-9

The engines currently in operation use Proportional-Integral control as a baseline. It has limitations.

- Interactions between fuel-oxidizer Mixture Ratio (MR) control loops and the thrust generated are observed in firing tests. It requires additional work to add decoupling and cancel them.
- There is no control during flight because some quantities, such as the MR, are difficult to measure.
- The engine must accommodate a wide range of operating points. This is due to variation in the launcher's acceleration, which changes the engine operating point, and run-to-run variation.

A more robust control strategy, the Linear Quadratic Servo Control (LQG/LTR), is selected. With this approach it is easier to decouple interactions and it provides a MR estimator during the flight.

LE-9 Control design flow using Simcenter Amesim

Developing a LQG/LTR controller for the LE-9 engine requires:

- a simulation environment able to generate a state-space representation of the engine, and
- a co-simulation capability with the controller development environment.

Simcenter Amesim provides these capabilities. The state-space representation can be obtained automatically thanks to the Linear Analysis tools. And the Simcenter Amesim - MATLAB®/Simulink® standard interface allows the co-simulation with models of the controller, in a Model-in-the-Loop (MiL) configuration. MiL allows fast development as you can make changes to the control model and immediately test the system.

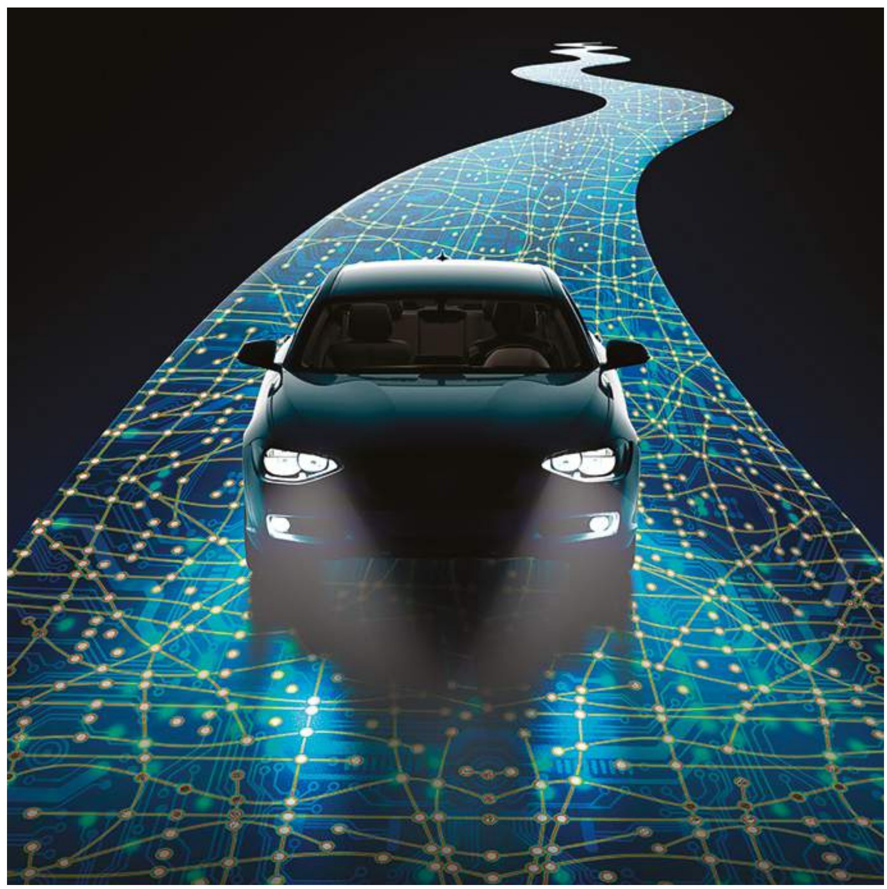
Conclusions

Siemens, MHI and Churyo Engineering have developed in close collaboration a framework for rocket engine transient analysis and control development. The methodology is now mature enough to be applied on current developments and should support MHI objective of a launch service price reduced by half compared to HII family and aims to be on par with SpaceX's Falcon 9. ■

Massive virtual validation and verification of ADAS and autonomous driving performance

Cloud or cluster-based simulation of thousands of scenarios in Simcenter Prescan360 in an orchestrated fashion

The advent of self-driving vehicles has a strong impact on the entire automotive industry. Developing an electric, autonomous, connected vehicle as a demonstrator of technology capabilities is one thing. Turning around an organization with a mature vehicle development process and the accompanying toolchain into a company that can meet the challenges of this revolution in people transport is quite another.



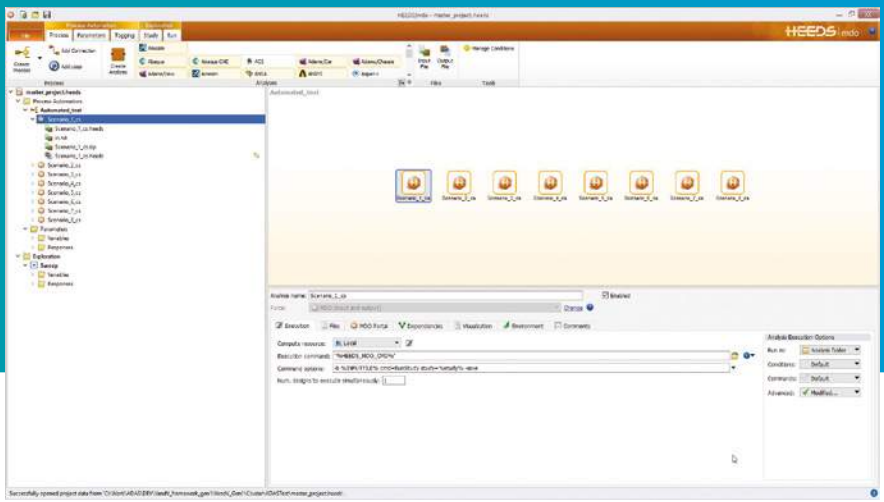
A new product development process is required to produce large quantities of these next-generation vehicles. If the ambition is to have millions of people being driven around through urban traffic directed by the control system of the vehicle, the system needs to be created in a stable, traceable and highly reliable product development environment. A paradigm shift in vehicle design is about to take place.

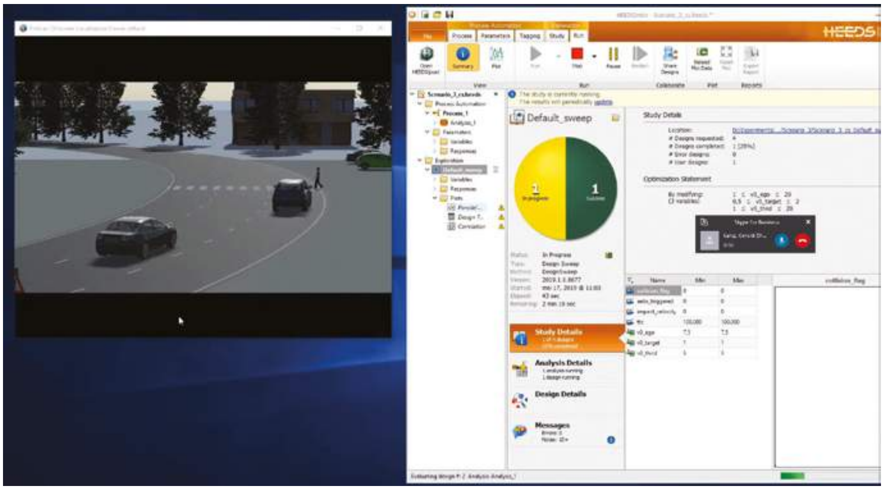
Solutions and modules in Siemens Digital Industries Software portfolio enable automatioan, design exploration, verification and validation for the development of autonomous vehicles at a system-, software and full vehicle level to drive a mature product development process for automated driving.

Challenges in developing autonomous vehicles
The most critical requirement of the vehicle development process is occupant safety. Shifting decision making responsibility from driver to carmaker to prevent accidents has a major impact on the development process. Carmakers will have to prove the thoroughness of their development processes and robustness of the vehicle's automated driving systems when people are getting injured or killed by wrong maneuvers from autonomously driven vehicles.

This implies that automated driving systems will have to react in a safe manner to all possible traffic scenarios under any possible weather and road conditions. The technology enabling this is complex. It requires a validation and verification process that allows for performance testing in a large number of circumstances. The process should be able to be repeated for different car evolutions over time, allowing performance comparisons for design exploration purposes.

Massive validation and verification framework
To cope with the previously mentioned challenges, Siemens Digital Industries Software is developing the Simcenter massive validation and verification framework, called Simcenter Prescan360. Starting from requirements





and vehicle-level system architecture, this solution makes it possible to generate endless numbers of virtual scenarios, combining world models with vehicle models connected through sensor models.

For each requirement, test cases are managed, potentially covering hundreds or thousands of scenarios. Using both Simcenter Prescan™ and HEEDS™ software, multiple approaches to automatically generating these test cases can be applied. Typically, it is done with script-based modeling functionality. Optionally, Simcenter Amesim software is the environment most commonly used for creating vehicle models capable of exchanging component or system models of different fidelity levels, optimizing accuracy and processing time. Simcenter Prescan representations contain the reflective properties for physics-based radar, camera, LIDAR (light detection and ranging) and ultrasonic sensors. The sensor models can therefore also be scaled from basic ground truth information up to full wave propagation modeling for detailed sensor evaluations. HEEDS is the orchestration and execution framework that automates the generation of the test plans and of the verification and validation process. HEEDS orchestrates the simulation of thousands of scenarios efficiently on the computational infrastructures of choice and manages the connection between requirements specification and the associated simulation assets.

Testing thousands of scenarios is easier said than done. With the Simcenter Prescan360, the majority of tests are executed in a fully virtual model-in-the-loop (MiL) manner. This means the vehicle, environment, sensors and controller are put together as virtual representations, as close to the reality as required to generate trustworthy results.

In practice this means the starting point is the generation of the scenario variants. There are multiple possible sources for scenarios. There are scenario databases like the GIDAS and CIDAS (German and Chinese accident databases, respectively), many OEMs and Tier 1s record traffic data and generate OpenSCENARIO format descriptions out of that data, and there are software solutions to generate scenarios synthetically. Simcenter Prescan has all the common scenario interfaces to support massive simulation in cluster environments. The generation, orchestration and execution of these large numbers of test is handled in HEEDS software.

Conclusion

The introduction of Simcenter Prescan360 is a breakthrough on the challenging road towards mass produced autonomous vehicles. The combined strengths of Simcenter Prescan and HEEDS have been the foundation for the launch of a new platform to confirm complete system and vehicle performance. Continued investments will further drive efficiency and coverage metrics, supporting our customers to introduce safe, reliable and comfortable self-driving cars. ■

Figure 1: FIAT 500e

Coupling 1D & 3D models for electric vehicles thermal management design

By Nicola Tobia and Matthieu Ponchant

Today's car manufacturers are making special efforts to come up with new approaches to design, development and testing for electric vehicles (EVs), where past experience, standards and know-how does not help and engineers and designers are basically starting from scratch. By adopting and using model-based system design, it will be possible to improve product development processes, reduce errors, and facilitate change management also for this new area. In fact, model-based development enables engineers to test the system in the early phases of the development within a virtual environment, when it is inexpensive to fix problems. Such model-based development is a process that enables faster, more cost-effective development of dynamic systems, including control systems, signal processing, and communications systems.

To assess the performance and energy efficiency of architectures early in the design process, coupling 1D and 3D models has proven to be a successful methodology to get accurate levels of modeling for more predictive simulations. This virtual methodology is implemented to improve development of electric vehicles, analyzing all systems and subsystems in different drive cycle scenarios. Fiat especially focuses here on thermal management design, as optimization of energy consumption has become of fundamental importance in electric vehicles, especially to increase autonomy. As a reference case to test the application study, the pure electric vehicle FIAT 500e, sold in United States since 2013, has been considered for this study.

1D-3D coupling has been used widely in different domains over the two

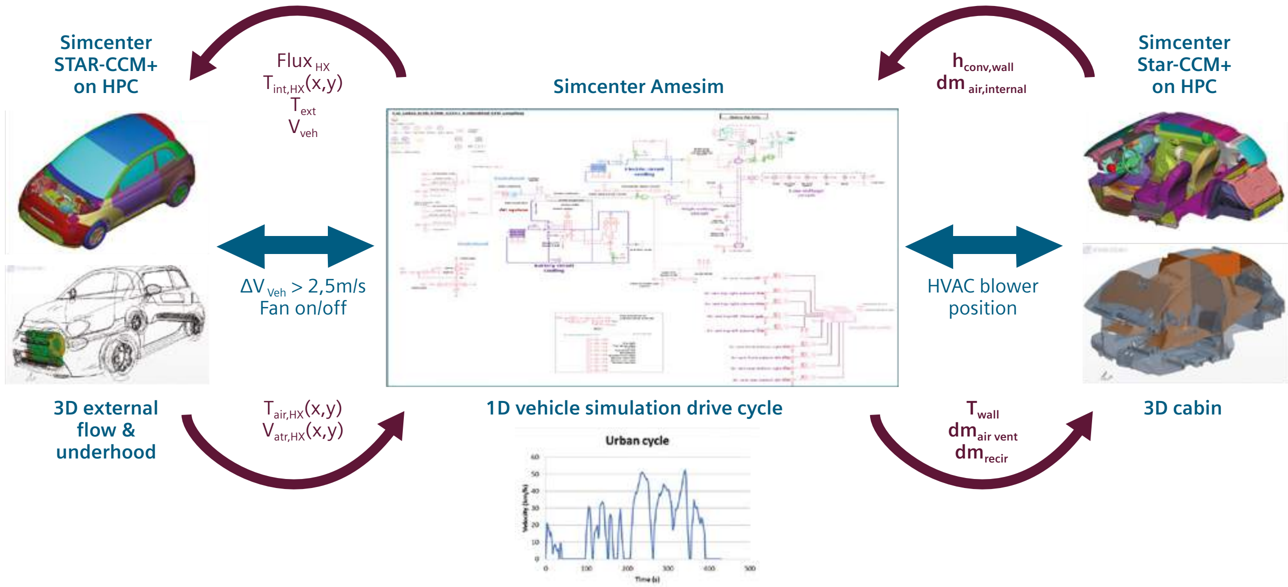


Figure 2: Coupling strategy between Simcenter Amesim 1D & Simcenter STAR-CCM+ for FIAT 500e

decades, especially in electronic, combustion or hydraulic systems. Such an approach is relevant for component design to enhance local behavior which cannot be properly modelled in 1D. Compared to existing methods, this new approach uses smart coupling between Simcenter Amesim and Simcenter STAR-CCM+ to integrate the use of high fidelity models for high performance computing (HPC) smart coupling. It is possible to connect several 3D models with a single one 1D model used as a "variable boundary condition" supplier along a transient scenario by using the smarter coupling strategy.

Using the right models

1D system simulation modeling is used to simulate components and subsystems of the electric vehicle (battery, inverter, electric motor, cooling system, HVAC and others), replicating how they work and which inputs and outputs are required or provided. They are mutually linked to simulate the behavior of a whole vehicle in real driving conditions. Focusing on the thermal management, such numerical simulations can provide information about the temperatures of each component and therefore the influence of the air-conditioning (AC) system on the vehicle range, through the electric consumption of the compressor. Simcenter Amesim provides all the required libraries and tools to rapidly create a digital reproduction of the overall vehicle systems. It includes functional models of:

- The electric powertrain (battery, inverter and electric motors),
- A 1D cabin model and complementary 3D cabin model (thermal walls are considered as well as average air volume temperature), and
- A thermal management model composed of battery cooling circuit, powertrain cooling circuit and AC system.

All parameters have been set according to existing data from the available FIAT 500e vehicle.

Even if a 1D model can connect all these subsystems of the vehicle, it cannot effectively account for some physical phenomena. This is the case of airflow and all its derivatives, where calculations need complex and expensive models. The only way to obtain a high-fidelity simulation is to use 3D models, in particular computational fluid dynamics (CFD). For this methodology, airflow is calculated in two different domains, which makes two 3D models: one vehicle model for the simulation of external flow around vehicle and under the hood, and one cabin model for the simulation of internal flow for passenger comfort.

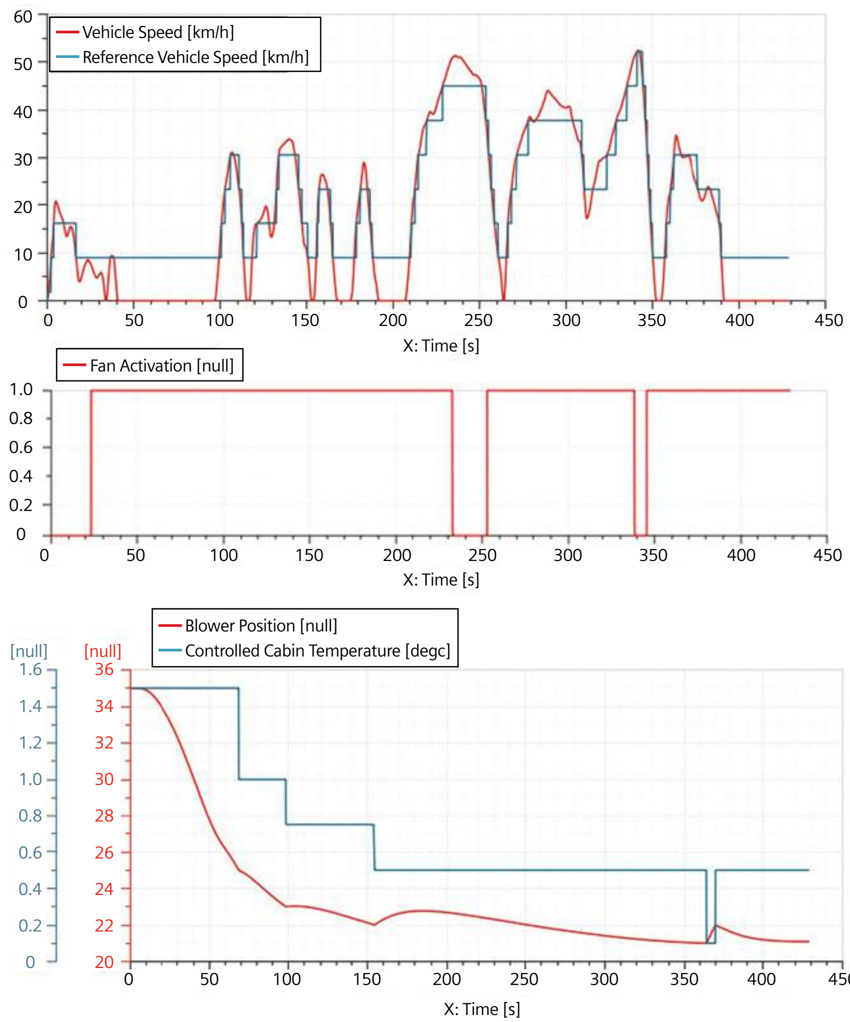


Figure 3: CFD vehicle and cabin calling

The methodology has been validated on different conventional driving cycles, like WLTC. The number of calls generated can be easily observed as in Figure 3 when a 3D vehicle model has been called, as each vehicle speed step of 5 meters/s, except at low speed, generates a call. The number of calls can be modified by changing the vehicle speed step: the lower it is, the higher the number of calls is. A minimal reference speed is not set at 0 km/h when vehicle is standstill, and therefore the 3D model runs with a minimal velocity. The 3D simulation with free convection will be investigated later. Real driving cycles have been performed at low speed (urban conditions) and at higher speed (extra urban conditions), and we can observe the same coupling mechanism, but with lower vehicle speed step (2 m/s instead of 5 m/s). The fan is activated because the condenser inlet pressure increases up to 25 barA but is deactivated when vehicle speed reaches 50 km/h or higher. The alternating current compressor electric consumption is not negligible in comparison to other electric devices. The powertrain cooling circuit is activated when the coolant temperature achieves 45 degrees Celcius. During the extra urban cycle, the blower position switches from high level to lower level in relation to the controlled cabin temperature. The influence of the blower air mass flow rate can be observed, especially between 365 seconds and 370 seconds, with an increase of average cabin temperature due to low blower air mass flow rate.

By simulating the flow field around a vehicle, under the hood and inside the cabin, CFD can provide all the information that is needed. Following this process, the great benefit is that boundary conditions are no longer estimated but are calculated through a 1D Simcenter Amesim model. Therefore, potentially every relevant instant or phase in a driving cycle can be studied in detail for each type of application. In the Figure 4, some 3D visualizations are shown, coming from WLTC simulation. In particular they focus on measures that Simcenter STAR-CCM+ calculates in order to use in 1D model, for both vehicle and cabin models.

HPC for predictive simulations to optimize energy-efficiency

The objective of high performance computing is to provide the computational power for the simulations needed for virtual design and validation phases. The main application that requires the power of HPC is the 3D simulation as it relies on resource-consuming data obtained from CFD analysis. 3D models are run separately on a HPC server through specific scripts based on call strategies, which are different for both models. The entire simulation with all driving cycle data that need to be considered Worldwide harmonized Light vehicles Test Cycles (WLTC) and Real Driving Cycle for urban and extra-urban) becomes affordable in terms of time: using ~300 CPUs, the whole simulation (1D model calling several 3D models) runs in a few hours, depending on the driving cycle duration.

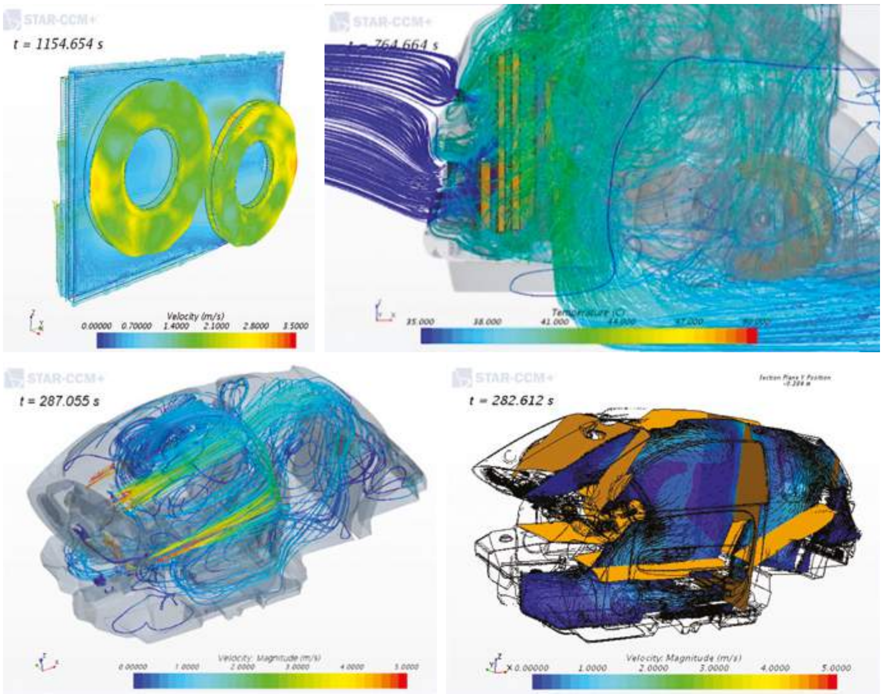


Figure 4: CFD results

With such a coupling approach, the overall simulation, even for long transient scenarios like a drive cycle, becomes affordable in terms of time and computational resources thanks to the use of HPC and smart coupling. 3D physical phenomena are still simulated with a 3D model, but in a more efficient way with variable boundary conditions from the 1D model, allowing a very high fidelity thermal system estimation for the electric vehicle and its components.

Furthermore, this methodology will be used to optimize the thermal management and energy consumption in the electric vehicle, by testing and easily assessing different thermal systems, such as heat pumps, in less than a day each. This methodology can be used at different stages of the product development cycle with functional sub-systems as well as more detailed ones.

This project, OBELICS, has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 769506. ■

"With such coupling approach, overall simulation, even for long transient scenarios like driving cycle, becomes affordable in terms of time and computational resources thanks to the use of HPC and smart coupling."

Nicola Tobia
CFD engineer,
Centro Ricerche Fiat S.C.p.A, Aerothermal department

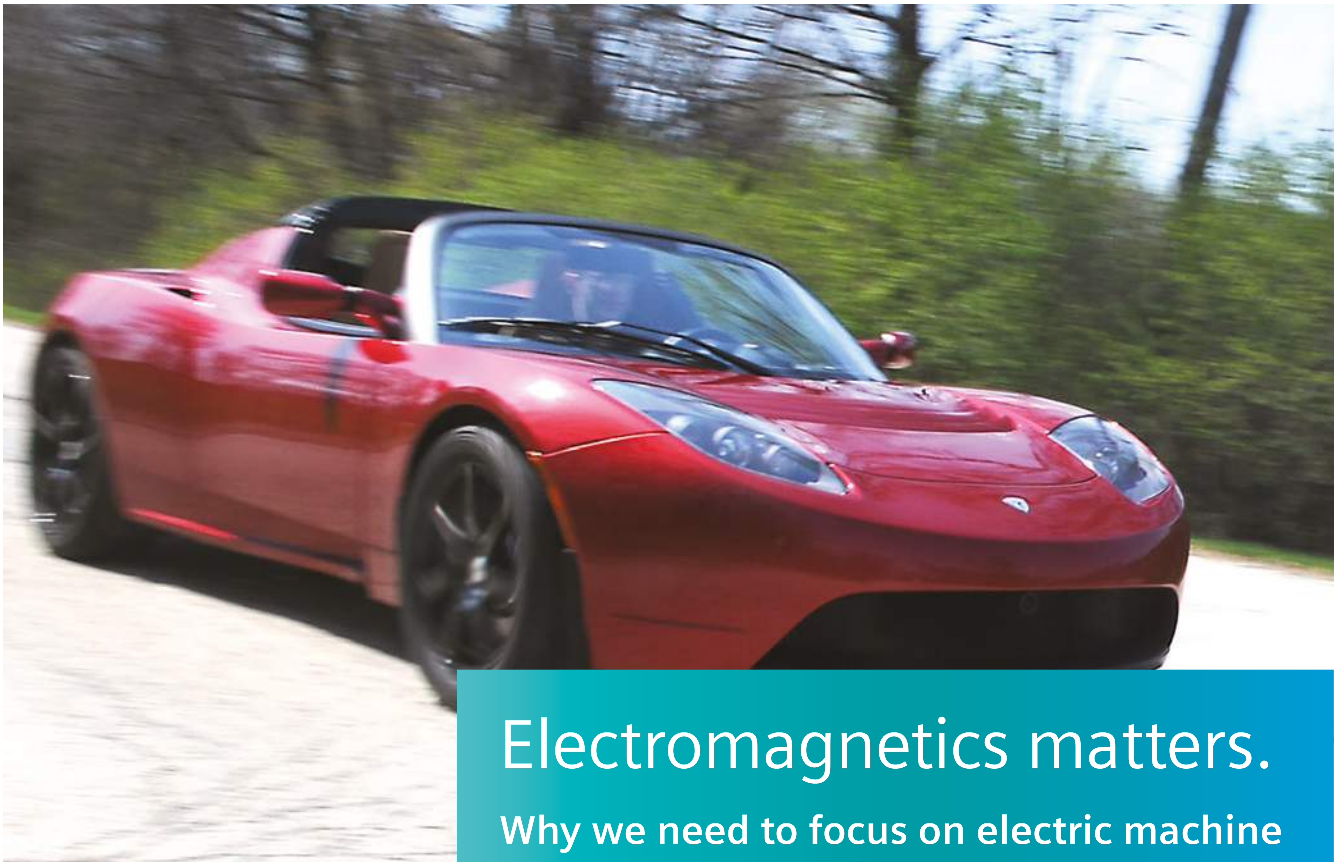


Figure 2: All-electric Tesla Roadster.
Image credit: US Department of Energy

Electromagnetics matters.

Why we need to focus on electric machine and electromagnetics design and engineering and how Simcenter can help

By Professor E.M.Freeman, FREng Professor Emeritus Imperial College London & co-founder of Infolytica Corporation

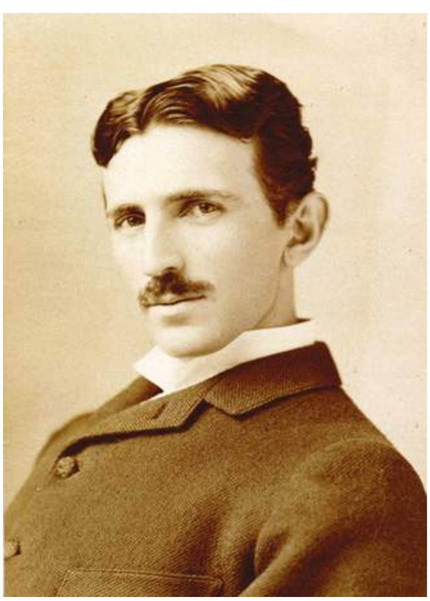


Figure 1: Photograph of Nikola Tesla, circa 1893 by Napoleon Sarony.
Image Credit: Wikimedia Common

Ask anyone how many electric motors they possess and most people will say three, possibly ten. In reality, this is more likely to be 300+. Think of all the stuff scattered around the house: kitchen, laundry and household equipment; hobbies; children's toys; computers; workshop/garage and gardening tools; air-conditioning; loudspeakers, headphones, chargers. And don't forget to add in the 50-100 motors per car. Then include all the devices used in commuting and in the workplace. And we haven't even touched on what happens when you need to fly to a meeting, or how all these electric motors interact and radiate. Your electric motor list can easily top 400-500 units. Take this all away and you are quickly back in the late 1800s, waiting for Nikola Tesla to come up with his idea for AC induction motors amongst other things. (A Tesla is more than just a pretty EV or a unit of magnetic measurement. Look him up if you don't know the reference. He was a pretty intriguing guy often regarded as a genius.)

Nikola Tesla and Tesla cars aside, it is clear today that electric motors and the related field of electromagnetics is grabbing our attention as designers and engineers. Call us pioneers, but we realized this a while ago. This is why, about 15 years ago, when we were Infolytica and still to become part of Siemens, we started on a project to assist machine designers with the design and performance prediction of electrical machines. The result today is Simcenter™ Motorsolve™, a complete design and analysis software for permanent magnet, induction, synchronous, electronically, and brush-commutated machines. In other words, it is a dedicated tool for electric motor and electromagnetic design and

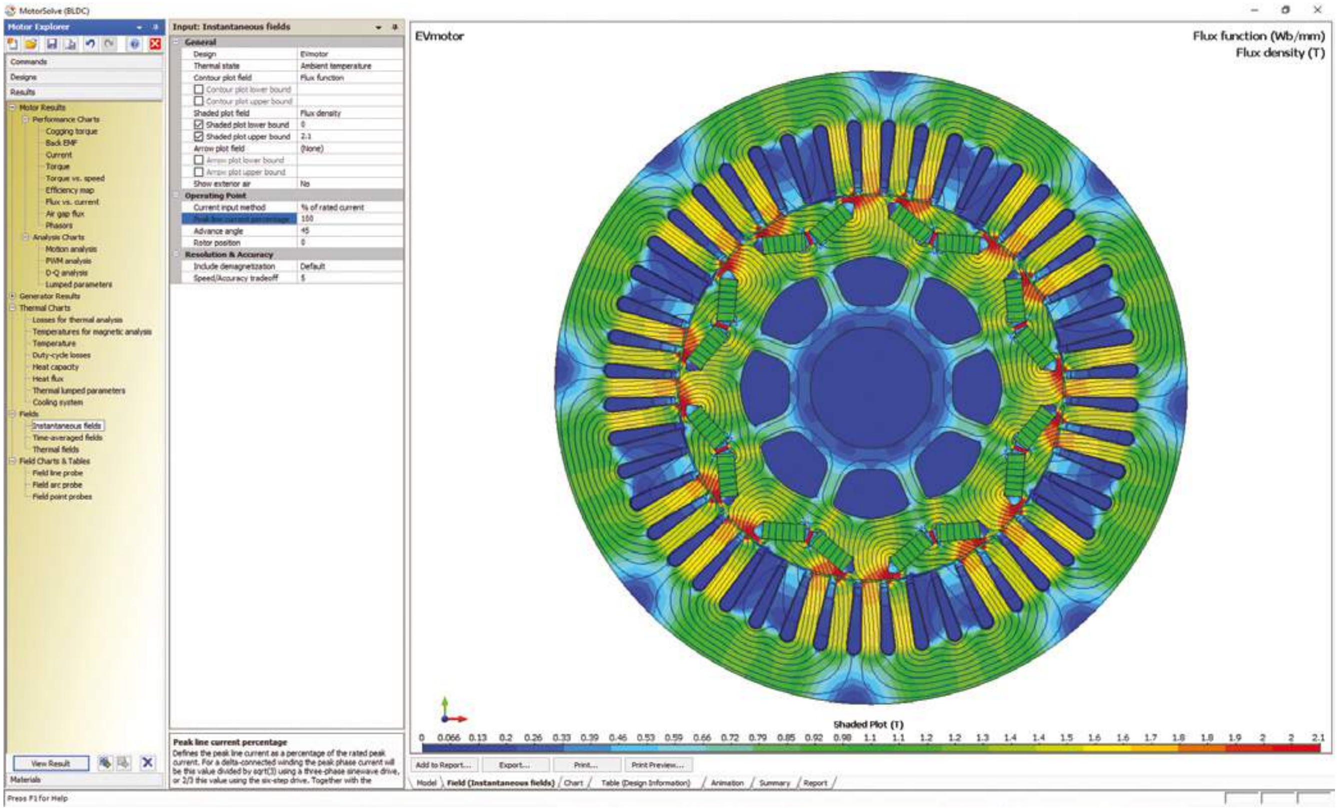


Figure 3: Instantaneous Ambient Temperature Field Plot of a EV motor in Simcenter Motorsolve

engineering visualization. Even better news is that the Simcenter Motorsolve interface interlinks with Simcenter MAGNET™ performance prediction software for motors, generators, sensors, transformers, actuators, solenoids, or any component with permanent magnets or coils. In a nutshell, two great tools that work together to make your life as an electrical machine and/or electromagnetics designer or engineer easier.

The liberal arts of engineering

As a discipline, electric machine or electromagnetics design requires a bit of a liberal arts approach to engineering. What sets the discipline apart from nearly all others is the nature and breadth of the expertise required. In short, an electrical machine designer, in addition to a deep knowledge of magnetics (and all things electric obviously), needs a strong working knowledge of structural design and analysis including NVH and acoustic issues, knowledge of CFD, cooling and all matters thermal as well as an understanding of electronics CAD, drives and control systems. And if this wasn't enough, advanced electric machine designs today are based on sophisticated mathematics. They need to be solved for tricky problems and variables like non-linear materials, time harmonics, transient conditions, specified duty cycles, to name a few.

NVH, CFD, CAD, what about electromagnetics (EM)? You probably noticed that no one mentioned EM in that list. It seems that those other disciplines require little or no knowledge of matters magnetic. Their various respective cross-couplings can be complex and complicated enough in their own right – why bother with electromagnetics? Right? Unfortunately, no. Making this mistake can lead to misunderstandings and, in the end, poor design.

Fortunately that situation is changing and software like Simcenter is starting to take a bit of the burden off designers and engineers as well. For example in CFD, some applications require knowledge of loss distributions in electrical machines. Where does the energy go? And what happens to it? To answer this, requires a close coupling between various solutions including fluid design, thermal management and

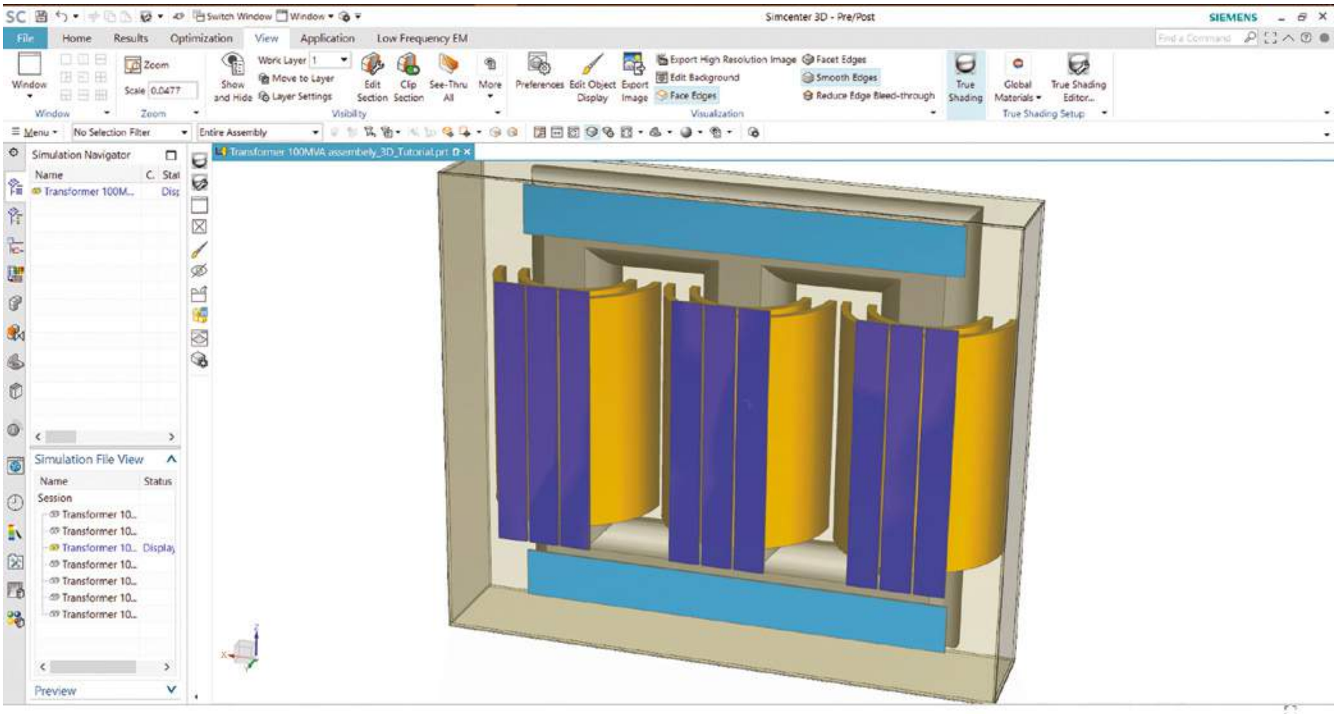


Figure 4: Power transformer modelled in Simcenter 3D. The recent electromagnetics module adds to the NVH, CFD and other multidiscipline capabilities

electromagnetics and electric machine design. (For the record, Simcenter Motorsolve has featured a thermal analysis link since 2008.)

Can I count on the software?
In an ideal world, cross-couplings should be solved as genuine closely interdependent problems. But there are always exceptions. For example, temperature changes can greatly affect the magnetic properties of various materials. How do you simulate that accurately? And, by way of contrast, even though many equations are the same in magnetics and some other disciplines, the underlying physics are not always the same.

So just to reinforce this point. Solving electromagnetic and associated electric problems requires some or all of the Maxwell equations – so make sure you brush up on your physics. (James Clerk Maxwell who laid the foundation for modern-day physics, was another genius, somewhat less flamboyant than Tesla.)

And one more point. One major concern is that some advanced electromagnetic topics seem to fall into a gap. They are not taught on undergraduate courses because the expertise is too scattered, or perhaps they are nor regarded as lying within the purview of the designer, or quite simply some issues just seem so "obvious" – until there is an unsolved issue, of course.

Bearing failures due in part to shaft currents.
Let's take a brief example. You might think this is out of place since this article deals primarily with electromagnetic and mechanical aspects of machine design. However, in practice, a large percentage of serious machine faults are due to bearing failure, and these failures are due to bearing currents. This is one of those tricky problems, where a machine operates for many years, faultlessly, and then suddenly breaks down. This has to be avoided at all cost. The breakdown is often due to some type of electromagnetic interference driven by electromagnetic fields (EMFs) that create some form of magnetic asymmetry that in turn create shaft/bearing currents. Nothing may happen until the oil film is punctured, but when this happens the electric field strength exceeds a critical value, and pitting occurs. Over time, this causes the bearing to fail. (Voilà, electromagnetics in bearings failures.)

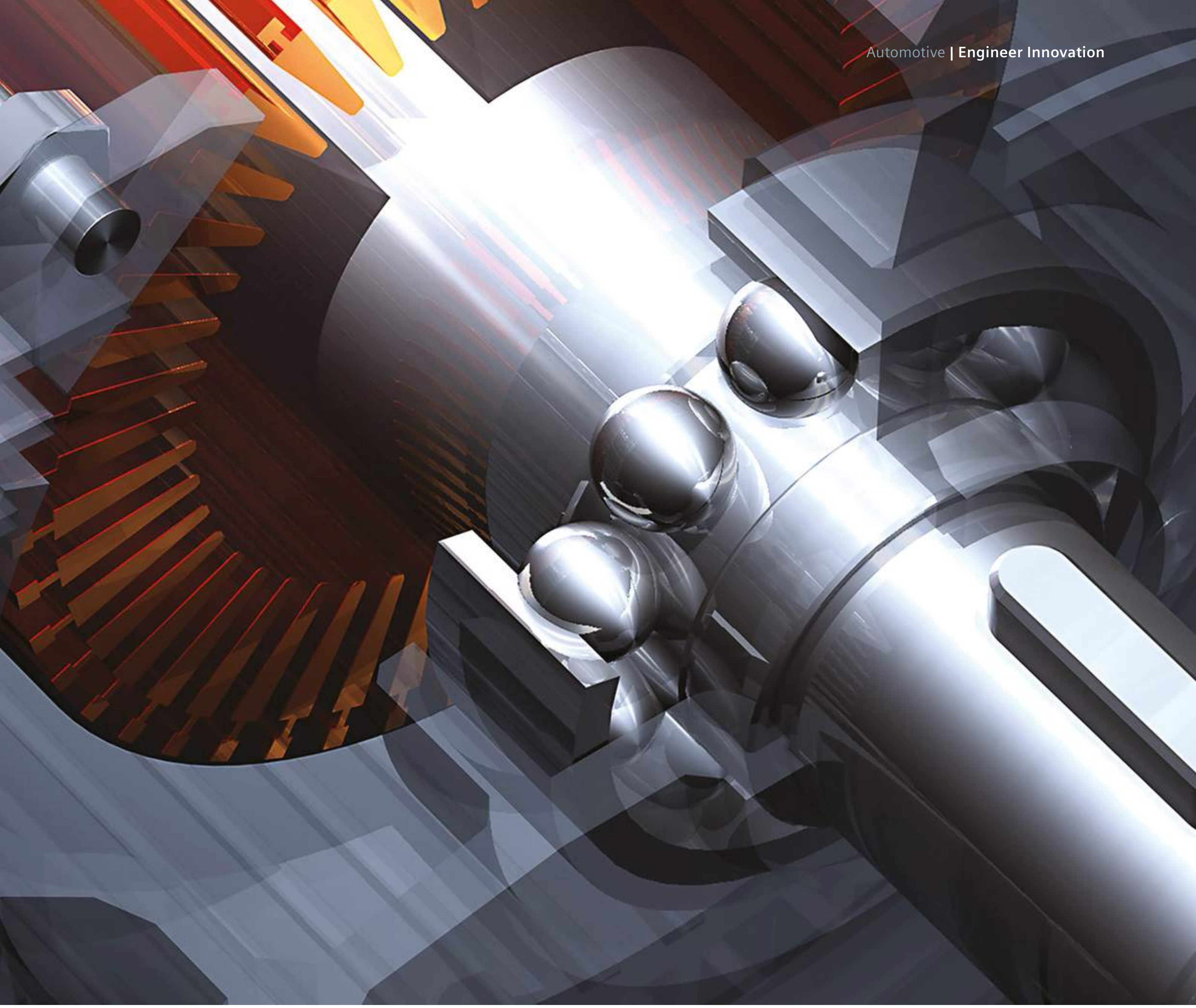


Figure 5: Ball bearing failure is often due to shaft and bearing currents

Magnetic asymmetry happens for several reasons including: poorly designed mechanical structures from a magnetic point-of-view; variation in magnetic materials from batch to batch (missed in materials testing); insulation faults leading to current leakage; and poor current imbalance. To solve this issue in simulation, an NVH structural model could be examined using Simcenter MAGNET and material variation effects could be studied, as could insulation breakdowns. Tools throughout the Simcenter portfolio can be interchanged so that engineers and designers have all the means available to address all these tricky electromagnetic issues and more.

So, my advice as a pioneer, think it through before you start and take a good look at the entire Simcenter portfolio to make sure that you are covering all the angles. It is just a principle of good engineering. Good Luck! ■

www.plm.automation.siemens.com/global/en/products/simcenter/

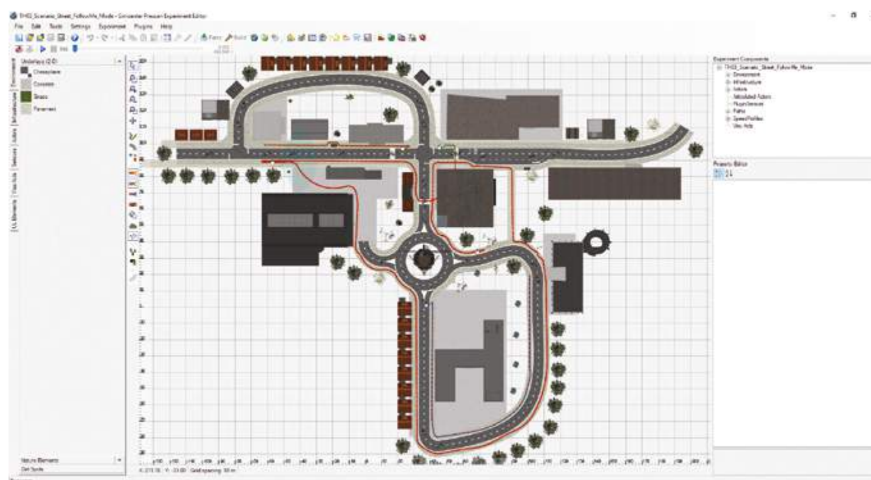

twinswheel
SIEMENS

Autonomous last-mile delivery droid manufacturer uses Simcenter software to gain competitive advantage with validated advanced safety mechanisms

Siemens Digital Industries Software solutions enable TwinswHeel to save time and costs

by streamlining technical choices, development and verification

Seeking a sustainable solution
Autonomous driving has been at the center of attention and innovation in the automotive sector for the past five years and this continues to be the case. With urban populations rising, movement of people and goods in big cities must be reconsidered. Indeed, online shopping growth plays a role in traffic issues and raises logistical concerns with new regulations and traffic restrictions. The challenge of last-mile delivery is therefore being taken up by many manufacturers. It is considered the most expensive and time-consuming part of the delivery process and needs to be addressed more efficiently.



Delivery drones and robots offer sustainable last-mile delivery solutions that are generating growing investments. Indeed, MarketsandMarkets predicts the autonomous last-mile delivery market will be worth $91.5 billion by 2030, supported by a McKinsey report, which mentions some organizations are forecasting that 80 percent of last-mile deliveries will be autonomous by 2025.

Capable of moving with little or no human input, autonomous vehicles combine a variety of advanced technologies and control systems. Detecting the environment, identifying the appropriate navigation path or obstacles and interpreting all this requires advanced sensing technology, computer vision, decision-making intelligence and complex mechatronic systems that are not usually incorporated in non-autonomous vehicles. Whether helping to carry heavy loads or solving the curb-to-door problem, a variety of cutting-edge technology is required.

Contributing to future urban logistics
After studying the market and the demand for this new form of delivery, TwinswHeel, a French startup founded in 2015, decided to design a robot that could negotiate city traffic restrictions and receive acceptance in cities. First, they developed the service for enclosed sites such as large factories and warehouses and semi-open sites such as hospitals and shopping centers. Now they are working at a larger deployment in the city of tomorrow to deliver e-commerce parcels or help craftsmen and people with disabilities carry their loads. Their goal is to design and manufacture droids that will contribute to future urban logistics. TwinswHeel's droids can move in two main modes: collaborative mode called follow-me or in 100 percent autonomous mode.

Coming from the automotive industry, Vincent Talon, chief executive officer (CEO) of TwinswHeel, says it was an obvious decision to create something with wheels to partially fulfill the role of a car. The first prototype had only two big wheels, but to stay competitive they adapted the architecture and created a platform with four wheels, which is closer to automotive and thereby provides benefits of scale.

“The development of our robots is guided by three main concerns: design a safe and reliable vehicle that meets customer demands, keep acquisition and ownership costs under control and shape an object that will generate empathy and therefore public acceptance,” says Talon.

To develop a technologically competitive robot, the TwinswHeel founders have gathered a team of 12 engineers, and since the beginning of the development of their robot, TwinswHeel more than doubled their staff with dedicated engineering divisions for mechanical, electrical, controls and sensors integration domains.

Safety first
After entering the mature and competitive industrial market, TwinswHeel's objective was to offer a new service in urban environments.

This droid is a great example of a new zero-emission service. In the city of Toulouse, France, it is used to assist Enedis power grid agents who repair the electrical network downtown, so they no longer enter the city with a van. On the other hand, Franprix Supermarkets uses the robot to help elderly or disabled people carry their groceries. Autonomous droids are currently being tested in Montpellier, France with La Poste (the national mail service) and STEF (European leader in refrigerated transport).

However, with these new applications, safety becomes the number one priority. Even if there are not yet regulations for operating these kinds of robots without human supervision, experiments are planned for 2020. TwinswHeel is working closely with the French government to create these regulations, and in this context, have been enrolled in pilot projects aimed at analyzing the acceptance level.

So currently, TwinswHeel's droids are required to meet the same safety levels as an autonomous car.

"We have a greater sensitivity to safety than our competitors," says Talon. "We respect the standards of motor vehicles because we consider the droid an autonomous vehicle."

The engineering team had to implement validation plans to check safety requirements. But these plans require millions of runs that are physically impossible to do. The inherent software and hardware complexity, the required massive validation and verification cycles and the growing number and variety of sensors require manufacturers to rethink their development processes. Simulation has become the indisputable innovation enabler for the development of autonomous vehicles. In this realm, the Simcenter™ software portfolio provides solutions and services to enable multi-domain designs exploration, verification and validation for the development of autonomous vehicles at a systems, software and full-vehicle level.

"We use Simcenter Amesim and Simcenter Prescan for model-in-the-loop tests to simulate the last developments and verify the requirements defined upstream are met. It takes less time and money than doing it on a real vehicle," explains Talon.

Sense-think-act
The engineering of an autonomous vehicle requires developing and validating complex sense-think-act functions. This requires an integrated system of systems, with mechanical, electrical and software components. For an optimized design, these components cannot be treated as separate elements, and software and hardware need to be developed in sync to achieve required hardware costs and system performance.

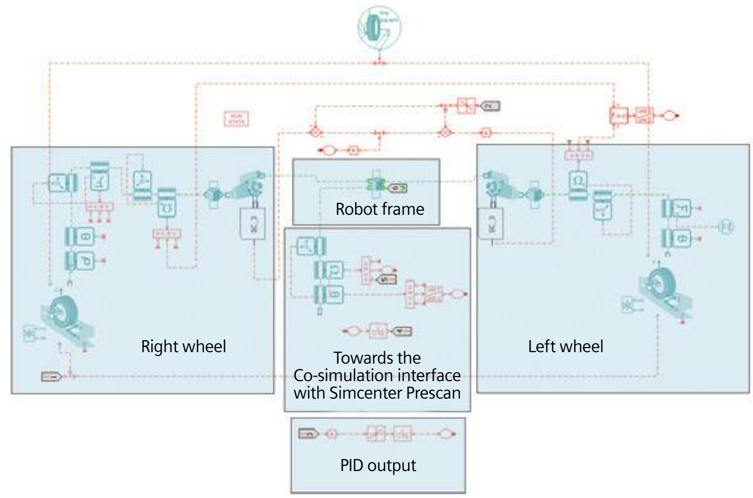
During live experimentations, the droid identifies and encounters many hazardous situations. Information is collected so the user can recreate the same situation virtually or generate a hypothetical one based on expert knowledge. When a critical situation occurs, the last 30 to 60 seconds of all robot sensors data is saved. This information is then used to create a reusable and configurable Simcenter Prescan™ software simulation scenario.

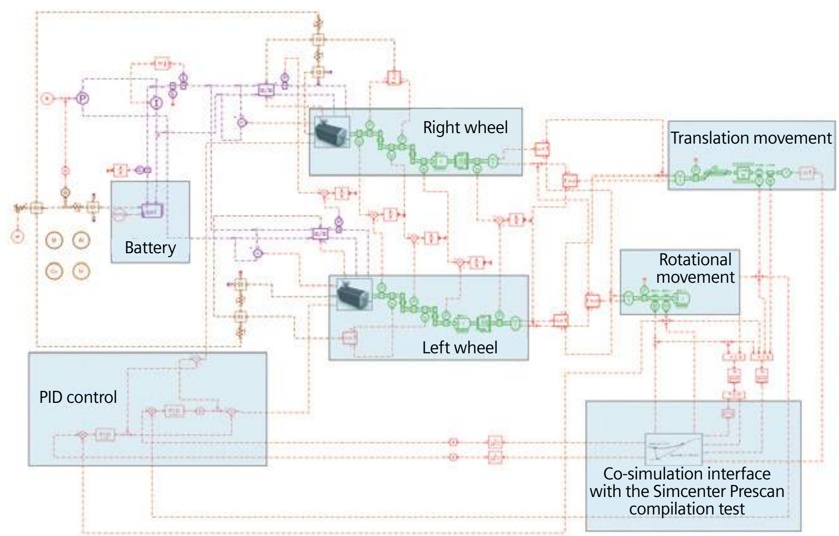
"Having those scenarios reproduced in a simulation environment using Simcenter Amesim and Simcenter Prescan allows us to build a catalogue of critical case scenarios for validation plans or future developments. The main advantage we find is these scenes are reproductible, leading to much easier iterative work," notes Talon.

To make decisions based on the environment, artificial intelligence (AI) is embedded in the TwinswHeel droid based on convolutional and deep neural networks (CNN/ DNN) trained with machine learning. Developing and validating the control and software strategies for any situation and environment is key for safety-critical functions and necessitates the use of closed-loop simulation. A typical example of a critical scenario is when a pedestrian suddenly cuts the robot's trajectory. In the scene shown below, the target pedestrian will cross a dense zone from the exhibition room composed of a lot of people and furniture. In this way, it will be possible to test the capability of the droid to manage the different obstacles it will pass. The representation of the scene in the visualizer below has the droid in the green square and the target pedestrian in the red circle. Depending on the location and the distances for the different obstacles, the droid will either stop itself, slow down to 0.5 meters (m)/per second (s) or continue tracking at a regular speed.

A Simcenter Prescan point cloud sensor model simulates the work of a lidar sensor. The sensors' data is sent to the Simulink environment for calculation and passed on to the perception part. The decision is made at the robot level and then the control part sends the instructions. All this is sent to the Simcenter Amesim™ software model, which interprets these instructions (for example, torque to apply to the two wheels) and provides the new kinematic and mechatronic state of the robot (droid pose) using its physical models.

This updated state of the robot is looped back to the Simcenter Prescan environment simulation, which then updates the information captured by the cameras, lidar, etc.





Integrating multiple complex technologies

"Many physical domains had to be combined to propose a reliable, robust and functional product to our customers," says Talon.

Indeed, the droid is equipped with two electric motors, a rotative 360-degree lidar for simultaneous localization and mapping, a stereo camera for target identification and obstacle avoidance and ultra-sound sensors for detailed mapping of close obstacles. Everything is manufactured and assembled internally, except the sensors.

"We use Simcenter Amesim to build models that enable us to select the vehicle architecture – for instance, to size the electric motor – as well as models to design and validate robot controls and supervisors of artificial intelligence supporting decision-making processes for droid movements," Talon says.

Using system simulation, startups can develop their solutions quickly by testing multiple variants and choosing the option that meets their needs. They can develop first models when little data is available in order to make first architectural choices, and then when suppliers are selected, it's possible to build more complex models, including mechanics, electronics and electrics. It enables companies to have complete models for sizing and controls design.

"Simcenter Amesim is the optimal software for multi-domain modeling," says Talon. "It allows us to combine the different physics of the robot and provides robust solutions, enabling us to move forward rapidly."

The decision part of the robot is the most complex system. To integrate the sensors, TwinswHeel uses a robot operating system (ROS) that enables it to get the sensors' drivers and plug them in with the rest of the software. ROS is a network that allows different software components to communicate, whether they are in C, Python, Matlab environment, etc. In the ROS, TwinswHeel creates nodes (software component) that can exchange information like the lidar point cloud. Calculating autonomous displacement of the robot's perception, tracking the master in follow-me mode, localization, path planning and control of the trajectory is carried out in these nodes.

Looking ahead

Components are constantly being developed for autonomous vehicles: new features and cases requiring more safety. The biggest challenge for TwinswHeel is to efficiently develop products to keep up with the car manufacturers' pace. "We are strongly inspired by what the car manufacturers do; we are on the lookout for everything they publish so that we do not search in a blocked path but go directly to a path that they have defined as the best," says Talon.

The worldwide competition is in full swing, mainly in the United States and China. However, in Europe there are only a few competitors mainly because of the protection offered by patents. This situation leaves TwinswHeel with a lot of room to develop.

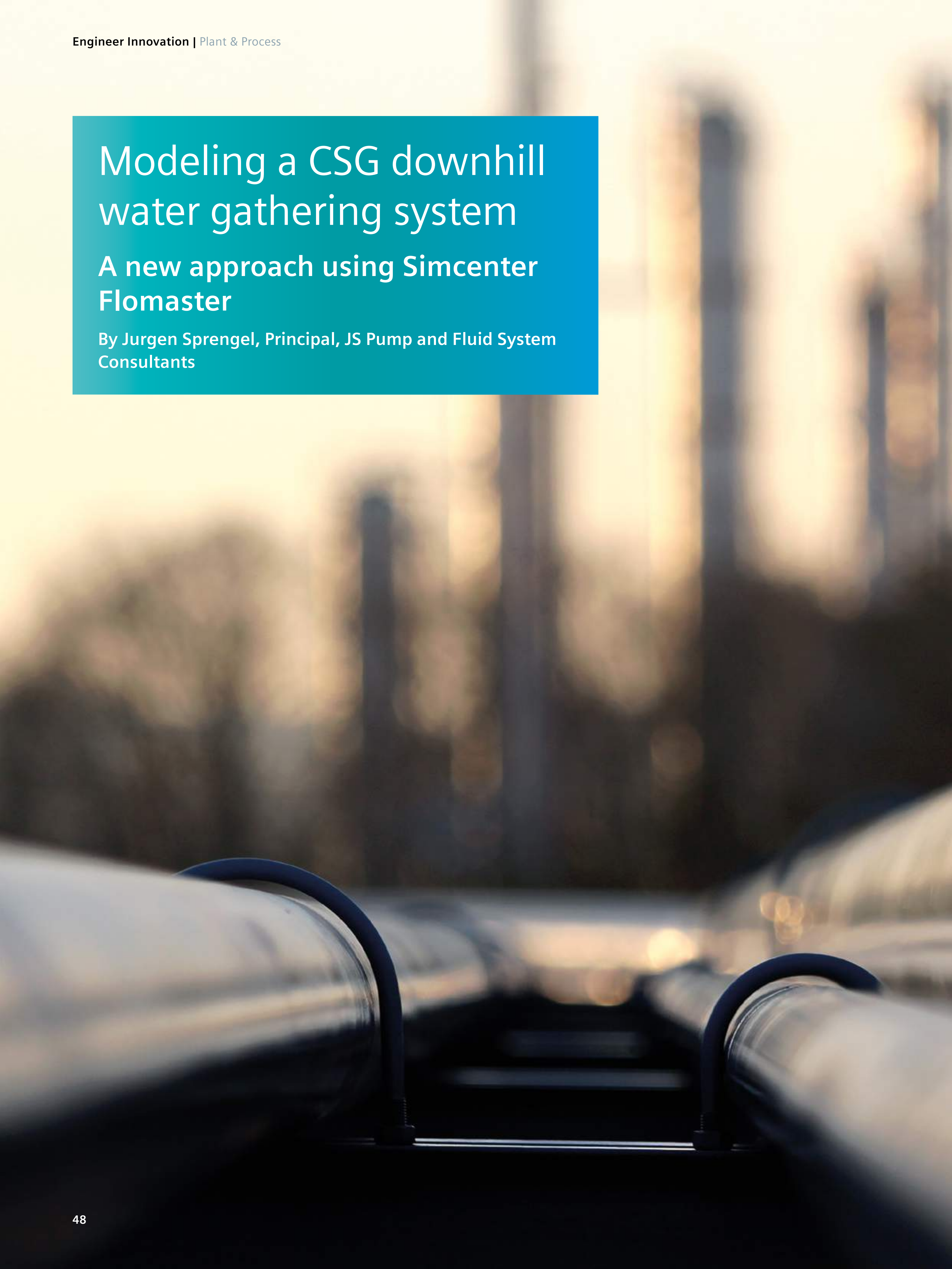
Today, with only a few years of experience, the company plans to offer a scalable robot. It will be a common mobile base that can support three platforms: a small version supporting 40 kilograms (kg), a middle-size version for 120 to 150 kg and a big one for loads over 300 kg.

Tomorrow, if European regulations allow an autonomous vehicle to move around without an operator, how many people will be ready to trade their shopping trolley for a robot? ■

Modeling a CSG downhill water gathering system

A new approach using Simcenter Flomaster

By Jurgen Sprengel, Principal, JS Pump and Fluid System Consultants



The coal seam gas story
Coal seam gas (CSG) has become a valuable new energy resource in Australia. In Queensland alone some 60 billion US dollars have been invested in this industry in recent years. More than 10,000 gas extraction wells have been drilled to date producing some 20 million tons of unconventional gas per annum. Gas and water pipeline networks of a total length of 12,800 kilometers (km) have been installed so far.

CSG project engineering includes the hydraulic modeling of both gas and water gathering systems. This is to identify the optimum pipe network configuration required to ensure a safe system at the best economic return for the investment.

The challenge
Hydraulic modeling of gas gathering systems has been very well understood in recent years. However, water gathering systems create some addition challenges, especially when located in hilly terrain. In particular, downhill running water gathering systems often include gravity flow sections where water column separation occurs. In such an event the laws of internal fluid flow no longer apply.

As pressure and temperate decline in the water gathering pipes, gas drops out of solution and forms small bubbles. These gas bubbles are swept along by the water flow and collect at high points in the water line where the gas is either vented to atmosphere by high point vents (HPV) or transferred into the nearby gas line.

The process of CSG extraction is generally achieved in three phases as shown in figure 1. Sometimes a significant volume of water has to be removed from the coal seam before the gas starts flowing at the intended commercial rate. Also, further wells may need to be added at a later date in order to make up for the declining rate of gas production within a particular gathering zone.

Gas volumes released inside water gathering pipelines are relatively small (typically less than two percent of total volume) and therefore insufficient to create an intense two-phase flow regime such as slug flow. Instead, free gas is swept along and accumulates at pipeline high points where it forms local gas bubbles.

Considering this build-up of gas bubbles at pipeline high points is of major importance in order to understand the hydraulic mechanisms at work. This effect is further amplified by the common practice of oversizing water gathering pipelines for the purpose of accommodating new future wellheads. This practice causes relatively low pipeline velocities and hence reduces any gas sweeping effect at high points.

In general, the volumes of gas accumulated at these high points are controlled by two principal HPV venting scenarios: (A) HPVs working correctly and (B) HPVs out of service.

Downhill water flow hydraulics
To demonstrate venting scenario A – HPVs working correctly, steep downhill sections are shown in the pipeline model (figure 2). The vertical elevation (high point to high point) is well in excess of 10 meters (m). Water column separation will occur in the event of the nodal high point pressure being below 0 kilopascals (kPa) gauge as HPVs will start admitting air into line. However, some HPVs may contain a non-return function, causing the water to vaporise in the downhill section as it cannot be depressurized below -95 kPa at ambient temperature. Alternatively, the downhill section may fill with gas until it reaches HPV trigger pressure of about 20 kPa gauge. Any further gas coming in will be vented at this pressure.

Venting scenario B – HPVs out of service is illustrated in figure 3. In this scenario the incoming gas is not vented but continuously accumulates thus "pushing" down the water column in the downhill leg until the gas bubble reaches the bottom of the bend. Any further gas

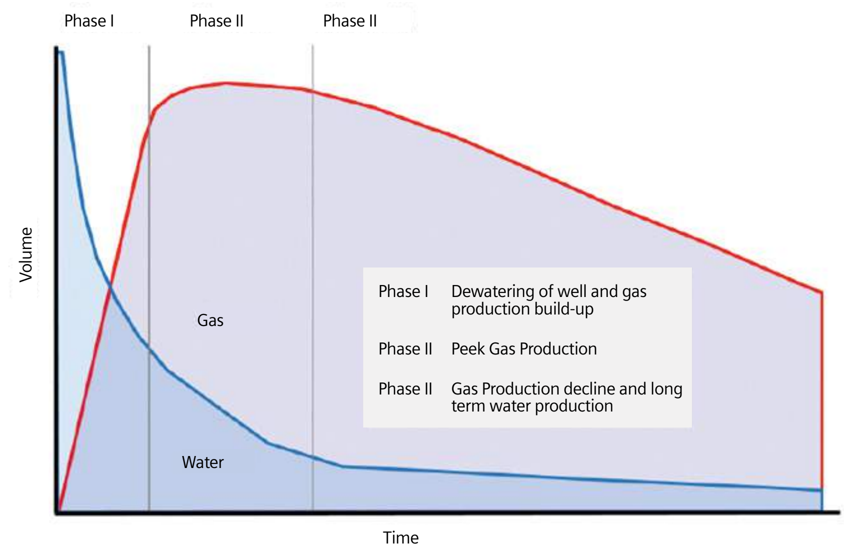


Figure 1: CSG well production phases - Source: Capital Energy Group 2014

coming in will now be able to escape from the bend. In this scenario gauge pressure, p1 will be equal to gauge pressure, p0 plus the static elevation, HSTA.

As can be seen from the below model in figure 4, the pressures in gas filled downhill sections will be accumulative as the downstream gas bubble will need to be "pushed" by the upstream gas bubble to overcome the water column in cup 2. This cascading effect will feed pressure back to HPV1 and therefore defines the backpressure the PC pump has to overcome in order to maintain its pumping rate.

Modeling of downhill water gathering systems

Shown in figure 5 is the schematic of a typical small downhill water gathering system. Pipe sections have been highlighted in red where disrupted gravity flow is expected to occur. The total physical extension of the below gathering system is about 8km x 8km.

The geometry of a water gathering system is usually described in shape files generated by geographic information system (GIS) software. Simcenter™ Flomaster™ software enables the import of complete shape files containing the coordinates of individual pipeline sections as well as their length and diameter. Such import functionality is very time efficient and enables the creation of a complex and realistic hydraulic model in a short time period. PC pump performance curves have to be added manually at each wellhead to complete the hydraulic model.

Shown below in figure 6 is the Simcenter Flomaster hydraulic model of the above typical downhill water gathering system which was created automatically from the geometry of the imported GIS shape file. Disrupted gravity flow functionally (HPVs out of service) was added to the model and is further described below.

PC pump performance curves shown in figure 7 have been added to the above hydraulic model which are the main variables during the simulation process. This typical water gathering system contains some high and several low water producing wells. While the majority of wells will start up early, the last well, WH14, comes on line some 311 days after

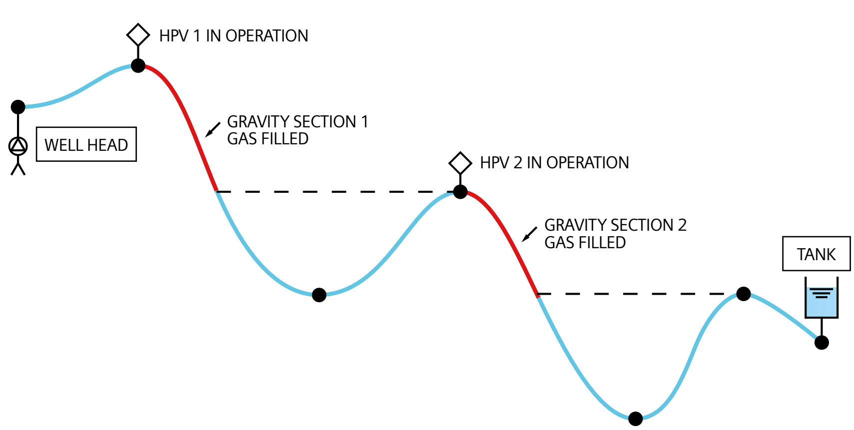


Figure 2: Downhill pipeline schematic – HPVs working correctly

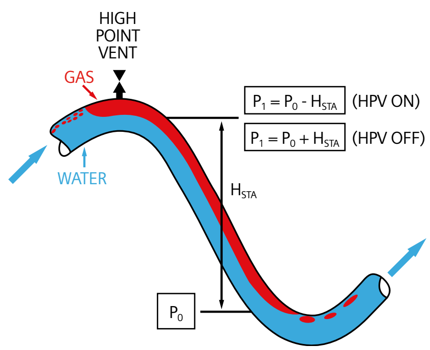


Figure 3: Gas bubble at pipeline high point

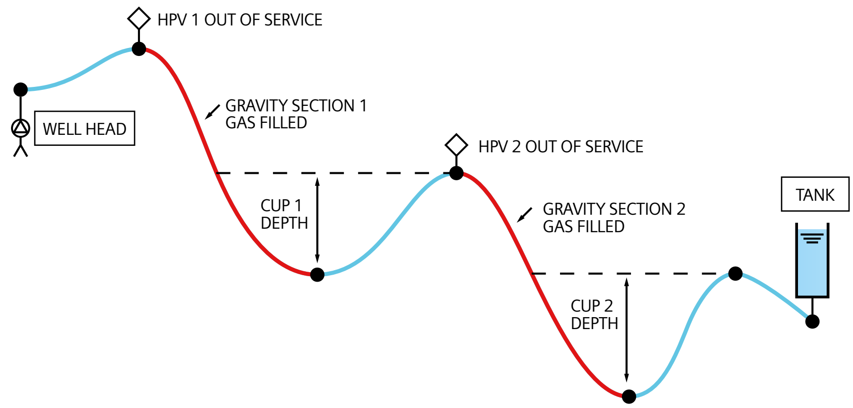


Figure 4: Downhill pipeline schematic – HPVs out of service

system start up. All PC pumps will operate at their pre-set flow rate for a considerable time period in order remove sufficient water from the well to cause the water level to drop just above the coal seam.

How to identify disrupted gravity flow sections

The first simulation run of a complete model is required to identify any disrupted gravity flow sections in the water gathering network. This task is accomplished by operating the unmodified model in "no vaporization" mode where water can sustain negative pressures. Following completion of this simulation the nodal pressure results at system high points will need to be interrogated. Disrupted gravity flow sections can be identified where the nodal pressure at the upstream high point is shown to be below –95 kPa.

How to determine a safe maximum allowable operating Pressure

It can be assumed that HPVs will normally function in good working order and hence will ensure relatively low maximum allowable operating pressures (MAOPs). However, with critical HPVs out of service as shown in Fig.4 HPVs out of Service, modeling results will always lead to more conservative MAOPs. Following this important acknowledgment, the hydraulic model in figure 6 has been modified by adding the disrupted gravity flow functionality.

Results for HPV venting scenarios A & B

For comparative purposes, two simulations have been performed, one with HPVs working correctly (Scenario A) and the other with HPVs being out of service (Scenario B). Note the hydraulic model in figure 6 only represents Scenario B (HPVs out of service).

Pressure results for Wellheads WH5 and WH7 are shown in figure 8.

Similar to the earlier downhill pipeline demonstration model, a significant increase in backpressure occurs when critical HPVs are out of service. This is caused by "pushing" gas bubbles trapped in disrupted gravity flow sections through the downstream "cup".

As demonstrated in figure 8, adopting Scenario B with critical HPVs out of service will always result in a more conservative approach when identifying a safe MAOP.

Optimization of pipeline diameters

The water gathering system hydraulic model shown in figure 6 including the disrupted gravity flow functionality is ready now for further system optimization work. The modified hydraulic model may be run through multiple simulations by varying important system parameters such as pipeline diameters and thus allows for checking and optimizing wellhead backpressures and the resulting pipe section pressure ratings.

Note that Simcenter Flomaster software, while in dynamic simulation mode, will complete an analysis of an average size gathering system in a matter of a few minutes. This functionally offers fast what-if system checks and enables the designer to carry out multiple optimization runs in a short space of time, thus helping him to identify the most economic gathering system configuration.

Results from pipe diameter optimization simulations

Three further optimization simulations (HPVs out of service) were performed by changing the main trunkline size in order to help identify a cost effective pipeline diameter.

The comparison in figure 9 of wellhead backpressures for various trunkline diameters indicates a moderate pressure increase for a smaller trunkline which may offer a more economical system configuration. An increase in trunkline diameter only gains a small reduction in wellhead pressure. Further economic analysis of pipeline capital cost versus pumping energy cost is required to identify the optimum pipe diameter.

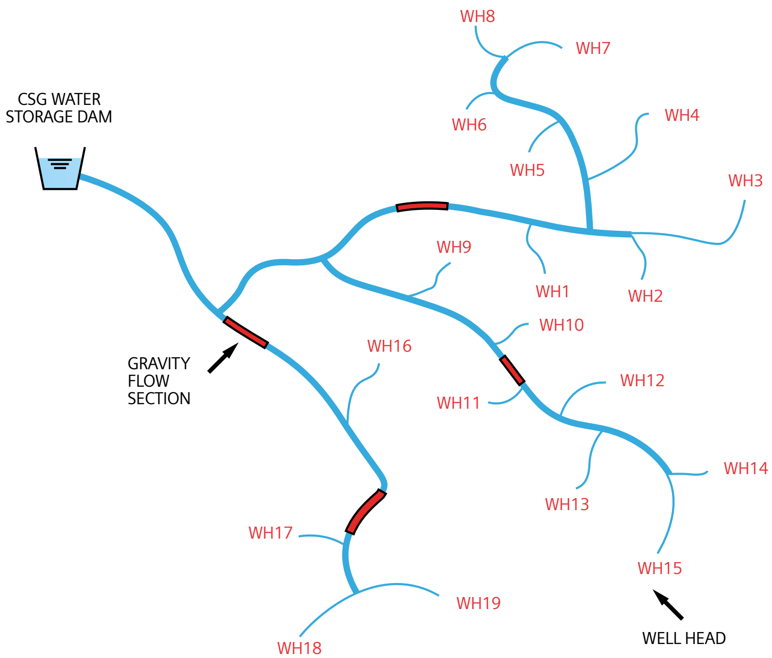


Figure 5: Typical downhill water gathering system schematic

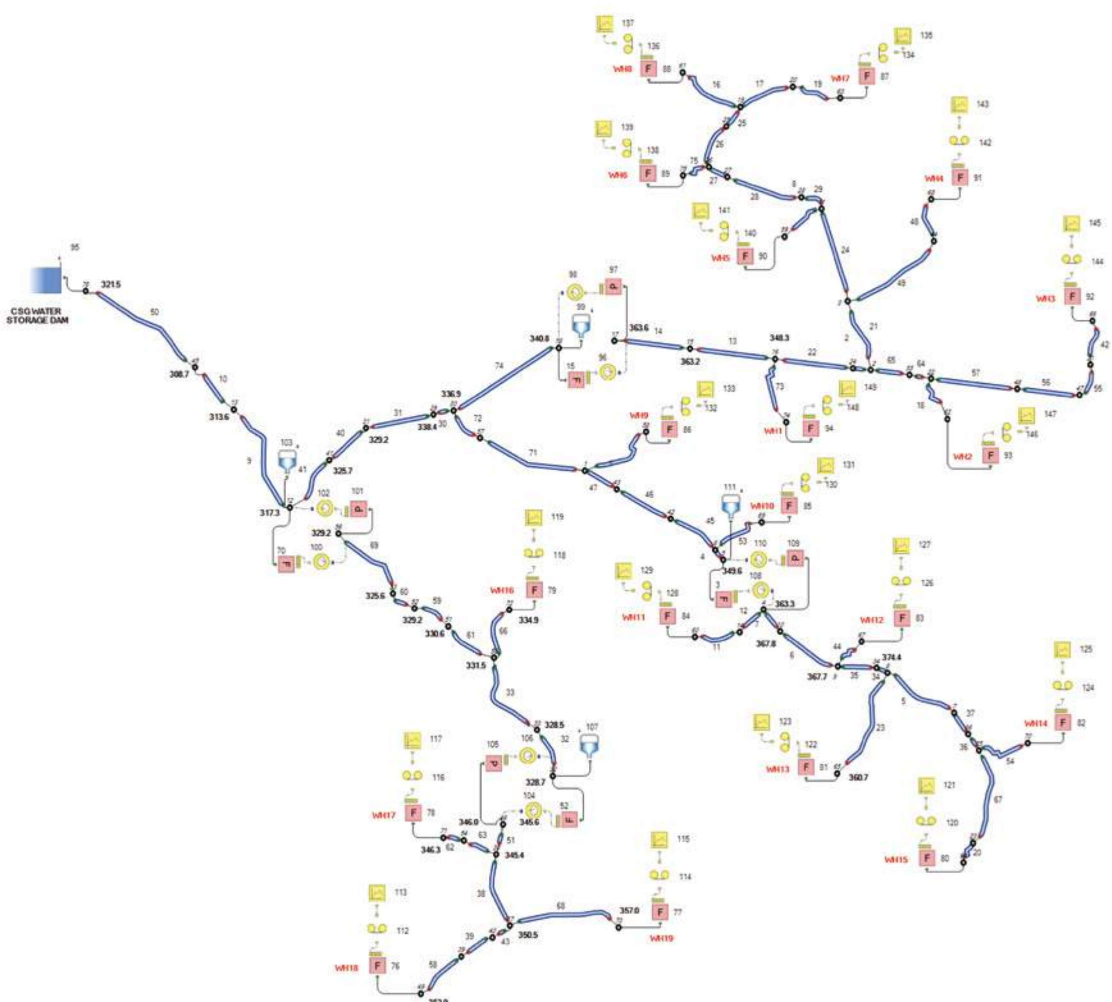


Figure 6: Hydraulic model of typical downhill water gathering system

The key outcomes

In summary, this method demonstrates the significant hydraulic effects disrupted gravity flow sections may have on the determination of required wellhead pressures and the selection of safe pipeline section MAOPs.

It further shows the key assumption of critical HPVs (located just upstream of disrupted gravity flow sections) being out of service will always result in the selection of a more conservative and therefore safer pipeline section MAOP.

The hydraulic modeling approach described enables a two-phase flow regime to be modelled in a single phase analysis process. Prerequisite for this approach is the ability of the software to accommodate hydraulic disruption as found in gravity flow sections.

By back feeding the downstream pressure and forward feeding the wellhead flow rate, it has been demonstrated the highly adaptable Simcenter Flomaster software can successfully accommodate these disruptive gravity flow sections.

The advanced functionality of Simcenter Flomaster software for water gathering system modeling will result in significant time savings and enable the designer to concentrate his efforts on system optimization work with a high degree of certainty.

A complete downhill water gathering system analysis enables the optimization of pipeline diameter. For example his showed sensitivity modeling of the main trunkline diameter versus wellhead pressure. Other pipe section diameters may also be worth further optimization.

Acknowledgements

The author expresses gratitude to the peer reviewer Pedro Milano, Principal Process Engineer of Arrow Energy, who provided valuable input into this paper based on his extensive design experience with CSG gathering systems. The author further extends his gratitude to Chris Peddy from Wood for his guidance. ■

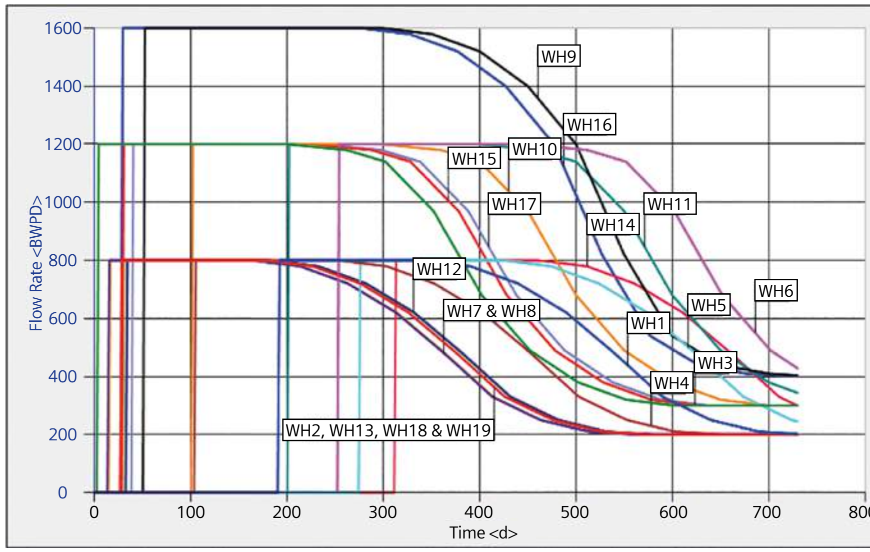


Figure 7: Wellhead flow rate versus time

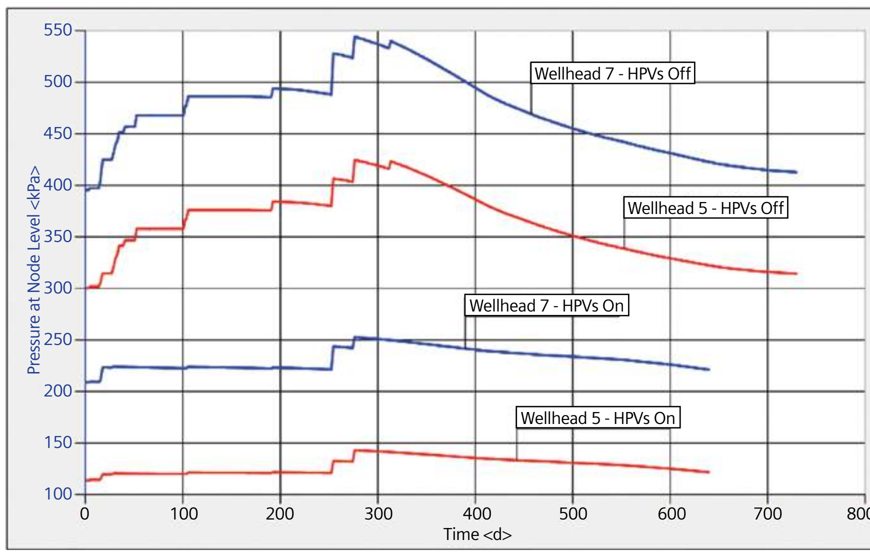


Figure 8: Wellhead pressures with and without HPVs in service

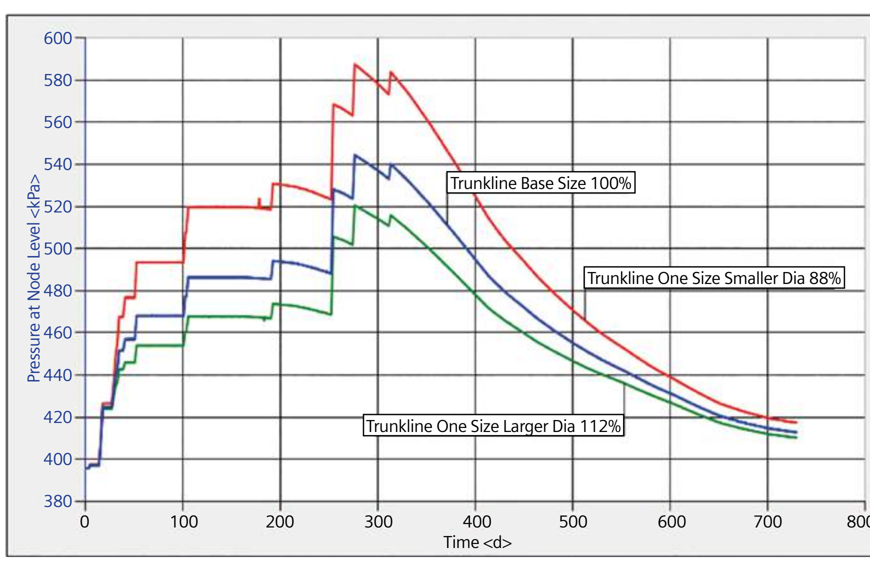


Figure 9: Wellhead WH7 pressure for various trunkline diameters

System simulation: comprehensive insights into mechatronic product performance

With more stringent regulations and shortened development time, OEMs and suppliers are tasked with offering more functions and options without compromising quality and performance. At the same time, products grow in complexity as electrification and software become more prevalent.

Manufacturers, therefore, need to accurately make design choices for each new option, component or system while balancing conflicting performances. The drastic increase in variability due to local market requirements makes this process even longer, results in a greater number of potential errors and adds difficulty in managing data and modifications. Moreover, industrial companies are exposed to strong pressure from new market entrants, higher speed of technology evolution and the emergence of new business models, such as unmanned taxi or car as a service.

One prime example is the helicopter market. Competition has become so fierce that manufacturers usually have no more than four years to develop their newest, most sophisticated models whereas production times a few decades ago could often take almost 15 years.

To stay competitive, helicopter manufacturers must validate systems integration earlier in the design process to reduce the development cycle time, costs and risk while also avoiding any issues that might lead to late deliveries which are subject to penalties.

"Being able to anticipate a problem is a significant source of cost and risk reduction," says Nicolas Damiani, expert in simulation at Airbus Helicopters Research and Development. "This approach allows us to master the development cycle and delivery time as well as to reduce our risk exposure related to the fuel development and integration activities that we usually face in such programs."

Frontloading systems integration

The key to success is improvements in systems integration with simulation to virtually evaluate product behavior and establishing collaboration between design, simulation and project teams. With system simulation, engineers create a virtual representation of their industrial product by considering various physical domains and technologies in an integrated manner. Using system simulation, manufacturers see how their system as a whole behaves in various scenarios and conditions to assess design specifications of the product in the virtual world.

Unfortunately, implementing system simulation often occurs at the end of the cycle. At this point, it's too late to do real troubleshooting. For example, in the automotive industry, a company could place the right engine, the right gearbox and the right powertrain components into place but everything working together leads to a shaky transmission. Simulation of the entire system earlier in the design process could have optimized the system. If ran at the beginning, the manufacturer would have already found the problems of the low-quality powertrain and associated costs in redesign and prototyping would be less. (Figure. 1)

Most engineering teams have a good grasp on their designs but they're still not yet fully integrating them, which leads to the discovery of issues later in the process. Without a comprehensive system point of view, the result could lead to failure. It is then crucial for companies to shift their simulation methods and processes to ensure a model continuity and any corresponding data management is correct.

Deploying system simulation

Historically, system simulation has been

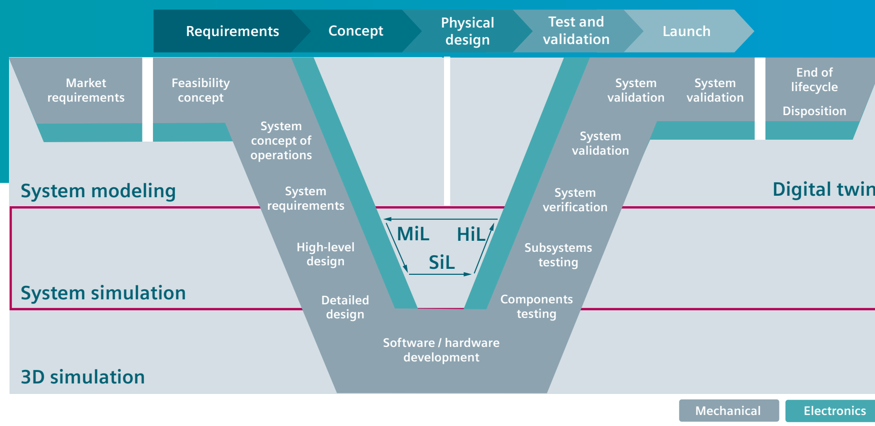


Figure 1: Engineering on the left side of the V-cycle consumes less than 5 percent of a program's cost but determines more than 80 percent of the product lifecycle cost [1].

in the hands of few. Those expert users still play a critical role in today's design cycle, but companies face the challenge of deploying and spreading model usage to project management. By not using a virtual model on a wider scale, costs of development and testing are increasingly burdening the bottom line. Meanwhile, silos mean that departments work separately and could possibly be independently simulating and testing their components instead of comprehensively as a whole system.

Today, in the context of large system simulation deployment, new categories of users appear. In addition to system simulation experts, new roles – such as system architects and system analysts – emerge. System architects oversee structuring the system simulation framework before sharing it throughout the company. Domain experts then fulfill modeling canvas stated by the architects and define the right level of complexity and details for each subsystem. Then, system analysts, such as program engineers or project engineers, use the created structures to run massive variant analyses to evaluate, optimize and validate design choices. (Figure. 2)

These new roles require rethinking company processes and methodologies around modeling, simulation, studies and analysis as well as data management. To answer this need, manufacturers must integrate capabilities between system architecture creation, modeling and simulation, and project deployment for system validation.

The disruption of system simulation
There's no industry that couldn't benefit from system simulation, and many will begin using the technology to work on innovative, smart products. Anything involving transportation, such as cars, planes, ships and trains, to industrial machinery or energy and utilities and even any smaller company, can face disruption without the use of simulation.

Interactions between multi-physical systems also require multi-disciplinary skills; thus, up-and-coming engineers will have to focus more than on a single discipline. The introduction of system simulation tools into the academic cursus is critical for grasping this knowledge and lowering the threshold for applying abstract concepts during student and research projects.

System simulation offers the ability to gain a massive amount of knowledge and understanding of the product behavior in early design phases, leading to rapid optimization of technology choices.

Along with breaking down the silos that often prevent various components from integration, decisions are made earlier in the design stage ensuring the product or system works as a whole. Early system simulation means product cost and time reduction.

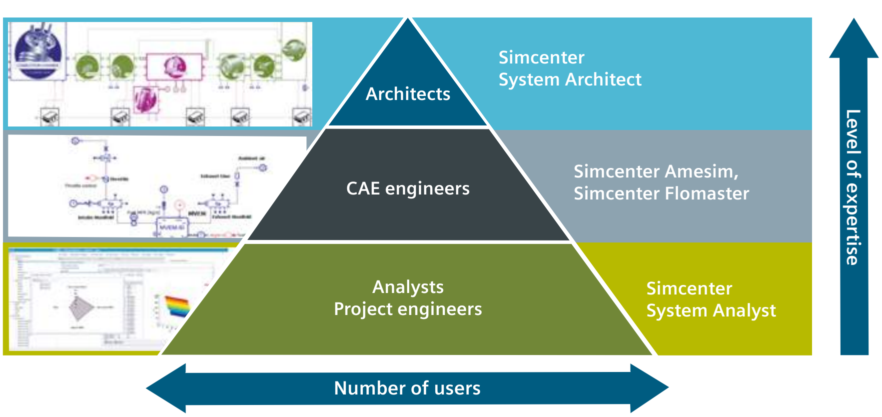


Figure 2: System simulation roles

References:
[1] CIMdata2018 Market Analysis Report Series: Simulation & Analysis Market Analysis Report, June 2018, page 30. ■

International Centre for Automotive Technology

Aiming for excellence in automotive testing and engineering

International Centre for Automotive Technology equips its new leading-edge NVH laboratory with Simcenter Testing solutions

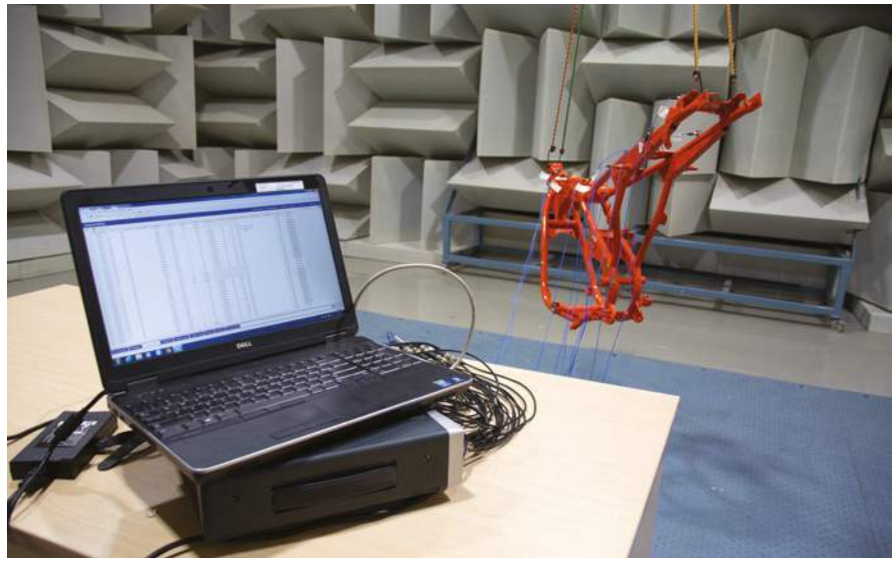
Unique project, cutting-edge infrastructure

The transportation industry is undergoing tremendous changes. Electrification, advanced driver assistance systems and autonomous driving technologies are creating new travel experiences for drivers and passengers. The growth and urbanization of the global population creates the need for smoother traffic flows. Digitalization is disrupting the way vehicles are conceived and making it possible to explore more unconventional designs. Is the industry ready for the change?

The National Automotive Testing and R&D Infrastructure Project (NATRiP) in India is one of the most significant initiatives to meet the challenges of the new industry. It is a unique collaboration of the government of India, a number of regional governments and the Indian automotive industry. Its purpose is to build a state-of-the art testing, validation and R&D infrastructure in the country.

The project aims to develop core global competencies in the automotive sector in India and to position the local industry prominently on the global map. It provides vehicle and component manufacturers in India with world-class, modern infrastructure for design, development and testing of components and full vehicles. The project will establish Indian service providers as leading partners on a global scale.

The International Centre for Automotive Technology (ICAT) was established in 2006 at Manesar, Haryana, India. ICAT has two centers in Manesar, providing quality services to support industry in the domains of computer-aided design (CAD),



computer-aided simulation (CAE), powertrain design and testing, noise vibration and harshness (NVH) optimization, fatigue testing, tire and wheel testing, passive safety improvement, electromagnetic compatibility (EMC) and more.

World-class equipment for NVH optimization

ICAT hosted the inauguration of new test facilities on 29th May 2018. The four new facilities in the test center include an advanced NVH laboratory, an EMC facility, a passive safety lab and a tire testing lab.

Approximately $22 million was invested in the NVH lab, resulting in a comprehensive facility for the testing and assessment needs of the industry. It includes several semi-anechoic chambers equipped with dynamometer capabilities that are suited for multiple vehicle types, from passenger to heavy-duty vehicles. The largest semi-anechoic chamber enables vehicle manufacturers to perform indoor pass-by noise tests in the room. These tests reproduce the noise level of a car passing by, to verify that the vehicle under test will meet noise level regulations.

The facility also features a room equipped for modal testing and analysis and a set of coupled acoustic rooms that are used jointly or independently for sound transmission loss and absorption coefficient testing. A listening room offers a quiet and comfortable space for assessing sound quality engineering (for example, jury testing). Advanced source localization tools, including an acoustic camera, significantly accelerate troubleshooting to save time and money.

"We are very happy and impressed using Simcenter testing solutions in our NVH center, because they offer the most comprehensive toolset for all NVH testing needs on one integrated platform."

Kiranpreet Singh
Assistant General Manager, NVH
ICAT

The laboratory manager, charged with equipping all rooms with adequate testing hardware and software, turned to the only supplier of an integrated hardware and software solution. The decision to work with Siemens' Simcenter portfolio resulted in a complete testing infrastructure covering operational NVH assessment, modal analysis, material testing, sound source identification and finally transfer path analysis. The combination of Simcenter SCADAS data acquisition hardware (with approximately 500 channels) and Simcenter Testlab software is well suited for mobile and lab environment testing. With this setup the ICAT testing teams easily pursue basic and complex testing campaigns with a single software and hardware platform.

"We are very happy and impressed using Simcenter testing solutions in our NVH center, because they offer the most comprehensive toolset for all NVH testing needs on one integrated platform," explains Kiranpreet Singh, assistant general manager, NVH at ICAT. "As our teams expand, the ease-of-use, short learning curves and flexibility of the hardware and software solutions were also important factors in our purchase decision."

With the help of the Simcenter portfolio of testing solutions, ICAT offers services and expertise for vehicle engineering, validation and testing with comprehensive, up-to-date accredited testing facilities. The NVH lab is suited for homologation and certification of all types of vehicles, from two-wheelers to buses, trucks and tractors. The test tracks and the large semi-anechoic chambers welcome heavy equipment machines such as construction equipment vehicles.

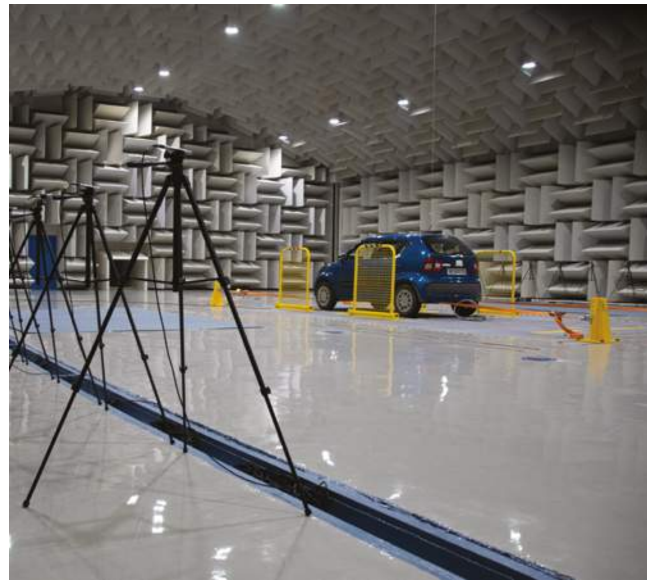
Fine-tuning the acoustic performance of a vehicle has never been as important as with hybrid-electric and battery-operated electric vehicles. Buzz, squeak and rattle noises, annoying ticks and clicks and irritating whining noises are no longer masked by the constant droning of the engine. The NVH lab at ICAT is perfectly geared to help manufacturers assess and perfect the noise performance of innovative vehicles and address future mobility challenges.

"The ICAT is a unique laboratory and the only one of its kind in this country and probably in the whole of Asia," says Dinesh Tyagi, director of ICAT. "The semi-anechoic chamber for passenger cars is suitable for simulation of pass-by noise tests, a capability that will be required more and more to develop quieter vehicles."

Serving industry needs with the most comprehensive test center in India
Beyond the NVH lab, ICAT relies on Simcenter testing solutions in the powertrain testing lab, part of the initial test center built in 2006. The powertrain lab uses Simcenter SCADAS data acquisition hardware and Simcenter Testlab software to evaluate and improve

"Simcenter Testlab fulfills our measurements analysis needs from signature testing to operational NVH measurements to model test, acoustics and transfer path analysis. All these can be done on single hardware and software platform."

Ikshit Shrivastava
Deputy Manager, NVH
ICAT



powertrain NVH. "Simcenter Testlab fulfills our measurements analysis needs from signature testing to operational NVH measurements to model test, acoustics and transfer path analysis," says Ikshit Shrivastava, deputy manager, NVH at ICAT. "All these can be done on a single hardware and software platform."

"The Indian automotive market has been growing at a very rapid rate in excess of 15 percent, sometimes up to 25 percent in various segments," says Tyagi. "It is expected that by the year 2030, the four-wheeler market will cross the 10 million units mark. Combined with the large two-wheeler market, we expect to see some 40 to 50 million vehicle units in circulation. Our center of excellence is geared towards the future, to help manufacturers develop vehicles that meet environmental constraints and regulations, and also to exceed consumers' expectations. We have been investing almost $8 million every year in our facilities to help manufacturers meet upcoming regulatory requirements." ■

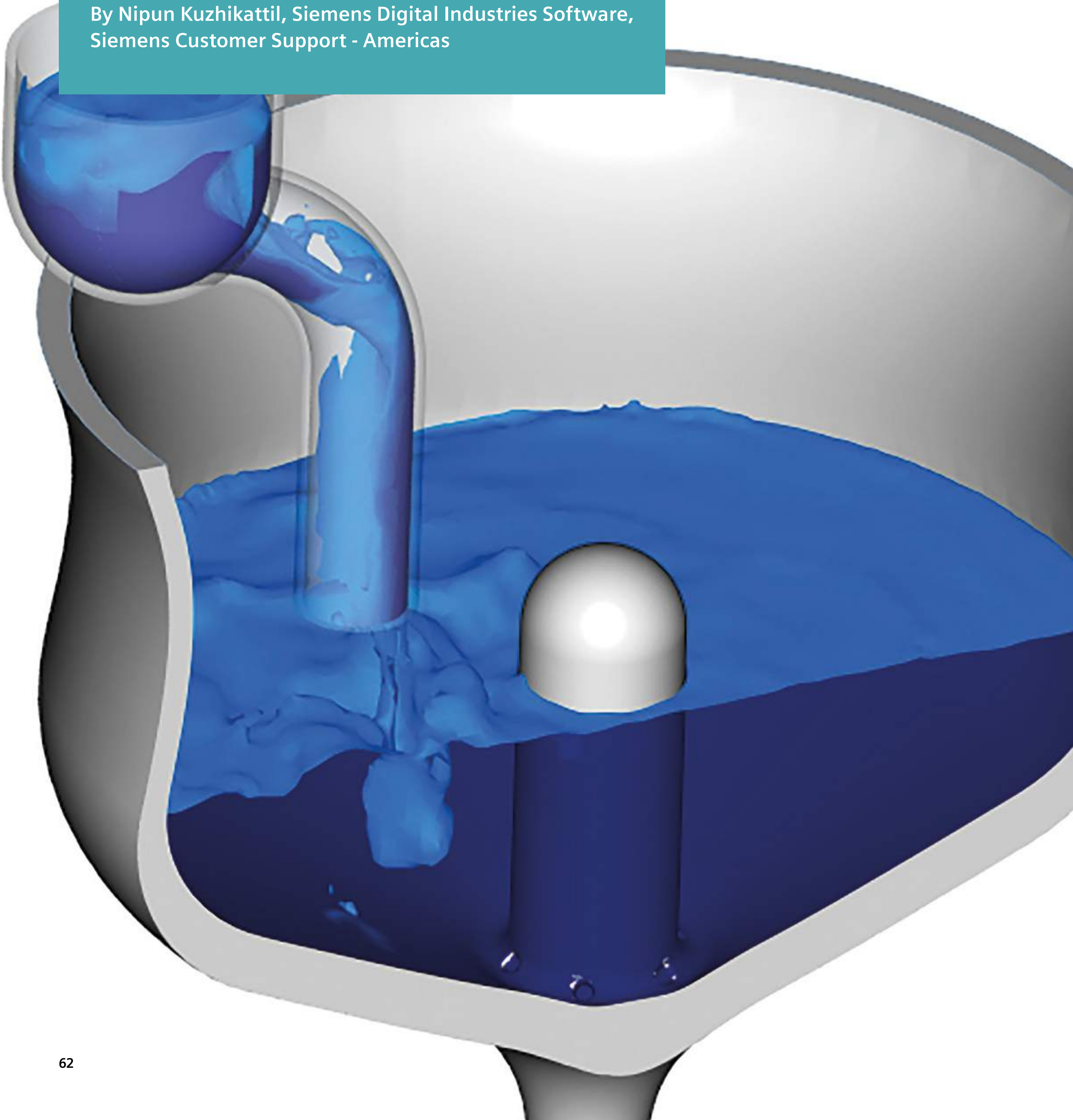
"We have been investing almost $8 million every year in our facilities to help manufacturers meet upcoming regulatory requirements."

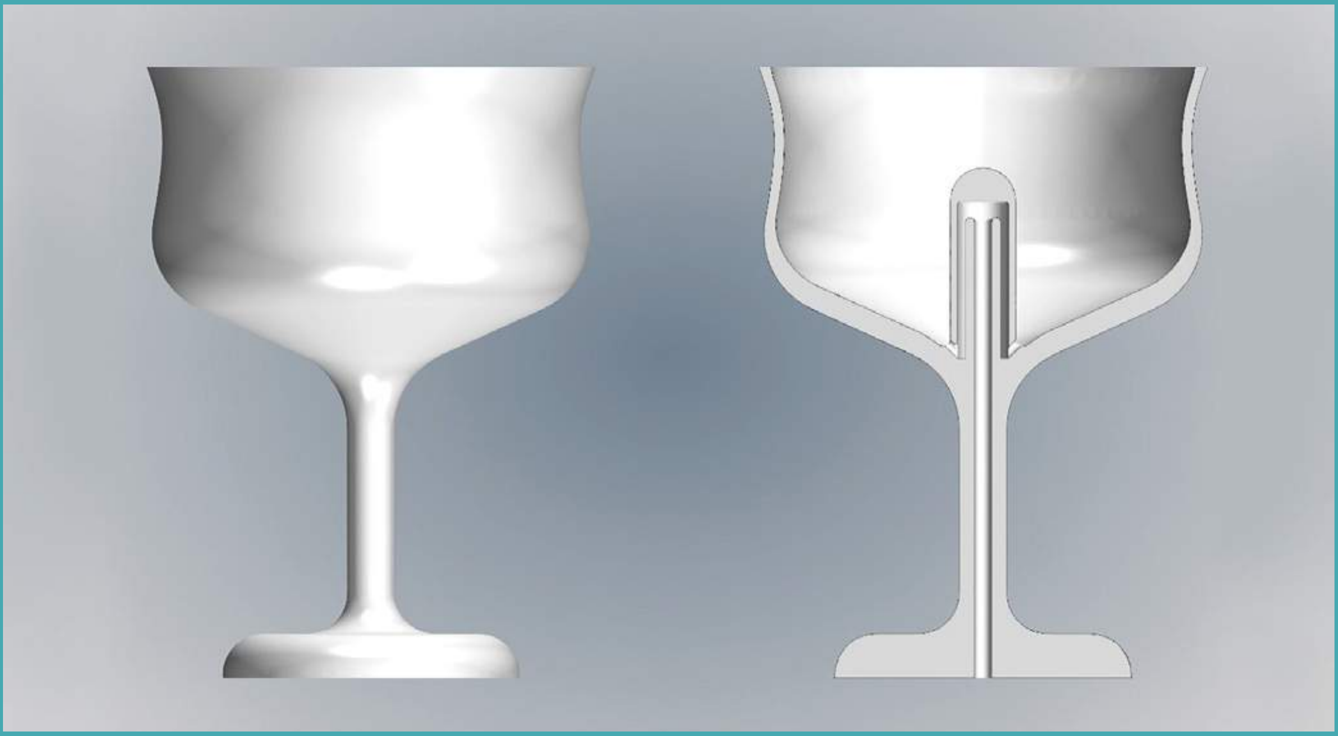
Dinesh Tyagi
Director
ICAT

Geek Hub

CFD and Additive Manufacturing – A Match Made in Heaven

By Nipun Kuzhikattil, Siemens Digital Industries Software, Siemens Customer Support - Americas





Let's begin with a story.
As with all good stories, this one is also from a long, long time ago, in ancient Greece, where there once lived a great philosopher. His name was Pythagoras of Samos, the man who gave us the famous Pythagoras Theorem, and many other reasons to love (or hate) mathematics.

Pythagoras was a learned man, and so he had many disciples. Like all good teachers, he kept his students on their toes. But unlike most teachers of today, he wasn't satisfied with just testing his students on geometry and number theory. He had a wicked sense of humor. After a hard day of study and learning, Pythagoras and his students would gather together and share a few glasses of wine – or so the story goes. Pythagoras decided to give them special cups designed by him. This cup is the Pythagorean Cup, popularly known today as the Greedy Cup. So long as his students took a reasonable quantity of wine in those cups, they could drink it without any fuss. But has there ever been a student who hasn't been greedy at the sight of free liquor? As soon as his students filled their cups with more than the usual measure, the entire cup would drain out and the students would be left holding empty vessels – and as the proverb goes, perhaps making a lot of noise.

The Pythagoras Cup is an ingenious device and a wonderful demonstration of the physics principle of siphoning. It's the same principle at work in bathroom flushes and while brewing beer. Like any CFD practitioner with too much time on their hands, this story gave me an idea – why not simulate this device? I've always been more excited by simple, physics-based simulations (lid-driven cavity, anyone?). It demonstrates the accuracy of simulation, while also illustrating the effectiveness of numerical modeling. And so, I turned to good old Simcenter STAR-CCM+ to simulate this. I had seen enough pictures to know what a Pythagorean Cup was supposed to look like. So, I created my own design using Simcenter STAR-CCM+'s in-built CAD capabilities.

I then ran this simulation on our in-house cluster. The video looked very convincing, if I may say so myself. With the latest feature in Simcenter STAR-CCM+ v2019.2 called "Screenplay", it has become incredibly easy to make very attractive animations. But this got me thinking even further – I knew what I expected to see, and I got it. But the proof of

the pudding is in the eating. Why not manufacture this cup and test it out? Validation and verification is the cornerstone of any design process.

With the advent of 3D printing, also known as additive manufacturing, it has become very easy even for non-engineers to create all sorts of objects – from household projects to automotive parts. This is the path I chose to go down. I approached a local 3D printing shop in Ann Arbor, and this is where I ran into my first issue – the 3D printing operation that fit within my budget was based on a process known as Fused Deposition Modeling (FDM). The nozzle that extruded the plastic material had a diameter of 0.4 mm. The thicknesses of the walls in my geometry was close to that value. I needed to be at above twice of that limit i.e. 0.8 mm.

Since my geometry was entirely built using 3D-CAD in Simcenter STAR-CCM+, it was very easy to modify my CAD parameters and regenerate the CAD. Just to be safe, I re-ran the simulation – again just a matter of two additional mouse clicks. The results didn't change by much, as expected. I then provided the modified CAD to the print shop. It took them approximately 14 hours to generate it. The printing process was followed by fifteen minutes of post-processing – shaving off the support structure and coating the part with a water-proofing aerosol.

It was now time to validate my design. I filled it with water and tested it over the kitchen sink, and voila – it worked! After all the years of performing CFD simulations, I shouldn't be surprised by this. But that thrill never seems to go away. But I wanted some concrete data though, with numbers. I set up a mock test rig using a translucent plastic box and a rudimentary camera stand using kitchen utensils. I filled it with water up to the initial starting point in my simulation and tested it –

Time to drain (simulation) = 16 seconds.

Time to drain (test) = 25 seconds (approx.).

That was quite a big deviation, and not what I was expecting. There definitely were enough problems with my test setup (a simulation engineer blaming the testing methods, that sounds familiar). For example, the least count of my measuring cup was 25 ml, while the total amount of water I added to initiate siphoning was 13.6 ml, so I was eye-balling quite a few of my measurements. But that's when I found a second issue – there was a slow leak in my component. In this video a secondary stream of water in addition to the primary stream flowing down the stem.

The cup was made from a standard 3D-printing material called as PLA, which happens to be hygroscopic. Every time I filled the cup with water, it absorbed more and more of it, making it even more leaky. The print shop had applied a water proofing aerosol, but it wasn't applied along the inside wall of the pipe through which the water drains out. Evidently, my trial runs over the kitchen sink had proved costly. Most of the advice I found online pointed towards re-printing the product with some modified printer settings. Alternatively, I could try using a 2-part epoxy called XTC-3D to coat the outside of the cup – this was the cheaper option, so that's what I did. The process is simple and well documented. It gave the outside surface a hard, glossy coat which would hopefully contain the water.

Time to drain (test) = 21 seconds (approx.).

This was a significant improvement, but not as much as I would have liked. If you look closely at the video, there's still a leak in the stem, where the walls are thinnest.

In fact, you can even hear the water inside the cup when it's shaken vigorously after the test. With the geometry I was dealing with, the only viable alternative was to invest in SLA or metal 3D printing and make a more durable product. I had learned a valuable lesson.

The moral of this story is not that we make better engineers by offering them free alcohol, although some of you might be tempted to think that. The key take-away from this story is the synergy between the use of simulation tools and advanced manufacturing processes, to rapidly accelerate product development. It has the potential to significantly reduce the cost of development, while making it possible to come up with complex, organic designs that can only be manufactured using modern manufacturing processes.

To see the videos, check out my blog: https://sie.ag/35EYMBd ■

Brownian Motion...

The random musings of a Fluid Dynamicist

Why I suck at Pool

I've always been a terrible pool player. Until recently, I attributed this complete lack of talent to my abysmal hand-eye coordination skills.

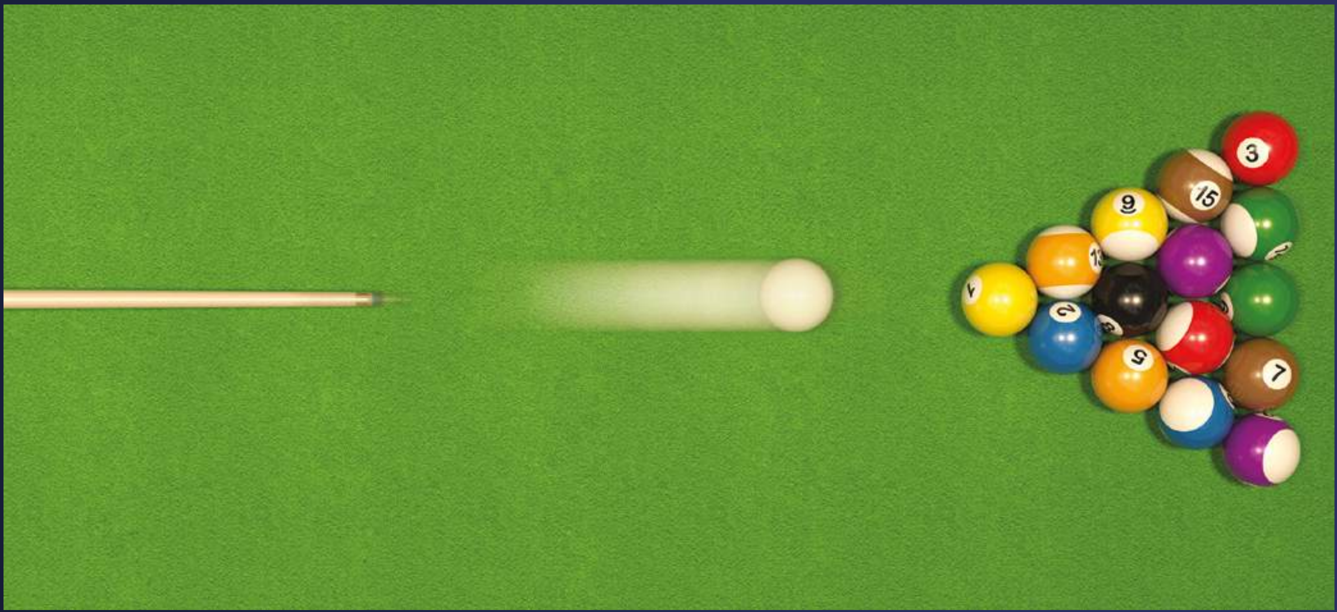
As it turns out, I may have been too hard on myself. It seems that my lack of ability is almost entirely because I fail to properly take into account of all the physical phenomena that influence the pool table when making a shot. More specifically, it's because I often neglect to take account of the gravitational attraction of the big dude sitting at the opposite corner of the bar. Let me explain.

On paper at least, calculating the elastic collision of two pool balls is a relatively trivial task, one that should be easily within the grasp of any high school physics student. Using Newton's laws of motion, given an initial velocity and angle of collision you should be able to predict - to a high degree of accuracy - the subsequent trajectory of the two balls. By taking account of the frictional rolling resistance between the balls and the baize, you would also be able to predict where the balls would eventually come to rest.

Having mastered a two-ball collision, it would be tempting to think that you could simply extend the calculation to take account of subsequent collisions (with other balls or with the rails of the table). However, even though each individual collision obeys Newton's laws, it turns out that as the number of collisions increases, the amount of physics you need to account for in order to maintain the accuracy of your prediction increases at a staggering rate.

In his book "The Black Swan", Nassim Nicholas Taleb describes a set of calculations by English physicist Professor Michael Berry that address exactly this problem:

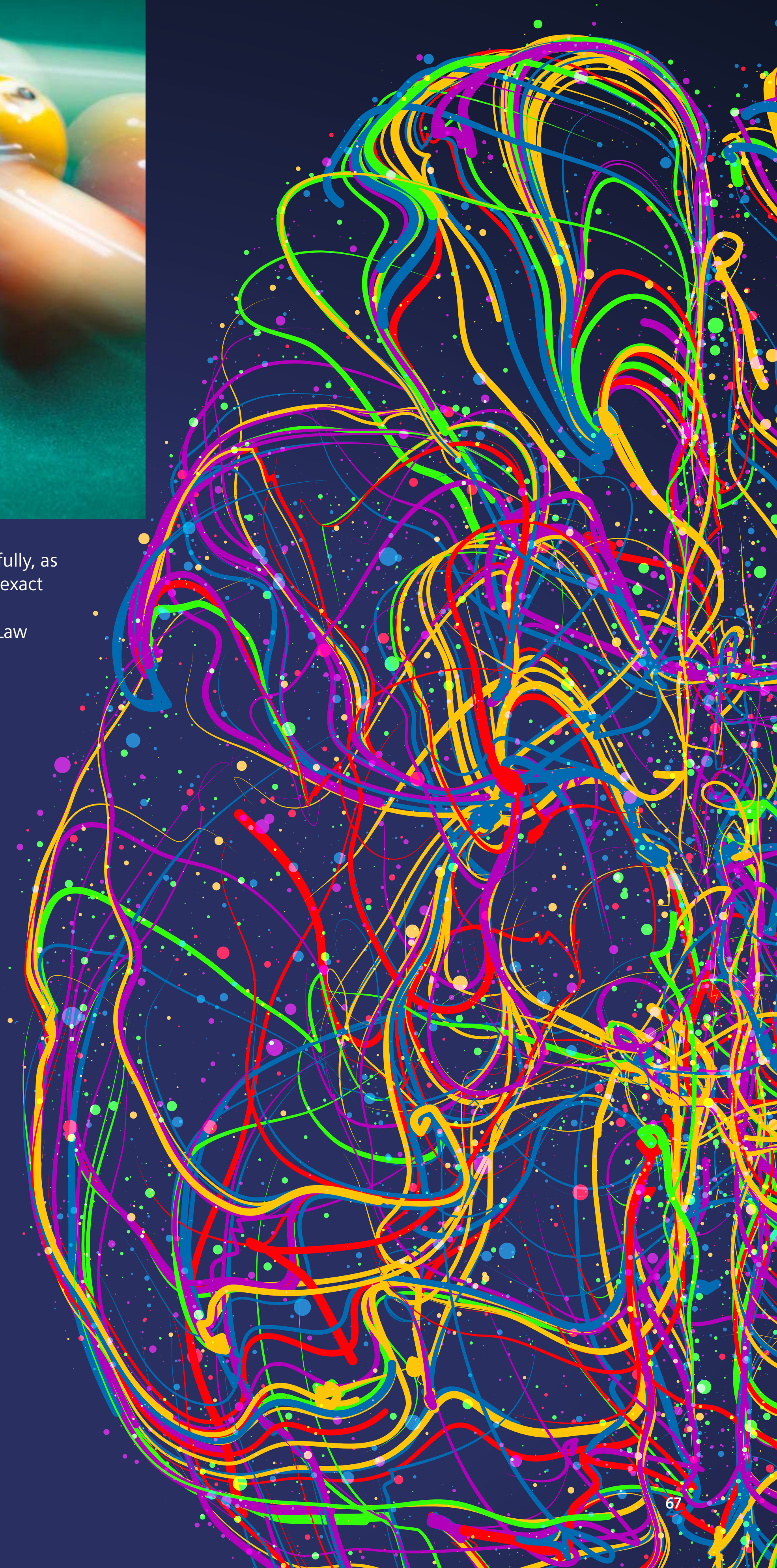
"If you know a set of basic parameters concerning the ball at rest, can computer the resistance of the table (quite elementary), and can gauge the strength of the impact, then it is rather easy to predict what would happen at the first hit. The second impact becomes more complicated, but possible; and more precision is called for. The problem is that to correctly computer the ninth impact, you need to take account the gravitational pull of someone standing next to the table (modestly, Berry's computations use a weight of less than 150 pounds). And to compute the fifty-sixth impact, every single elementary particle in the universe needs to be present in your assumptions! An electron at the edge of the universe, separated from us by 10 billion light-years, must figure in the calculations, since it exerts a meaningful effect on the outcome."



Obviously, this is an extreme example. Thankfully, as engineers, we are rarely called upon to make exact predictions such as the one described above. More often than not, we are rescued by 'The Law of Large Numbers,' which allows us to make deterministic predictions about phenomena that are stochastic. While we may not be able to predict the outcome of a ten-collision pool shot accurately, we can easily calculate the bulk effect of billions of air particles randomly colliding against a wall.

Extreme or not, this example does illustrate how even apparently simple engineering systems are influenced by easily neglected physical phenomena. It also demonstrates that the accuracy of a prediction depends, at least in part, on the amount of physics you capture in your model, and that capturing 'all of the physics' is rarely an option.

Finally, it also explains why I am so bad at playing pool. At least, that's my excuse, and I'm sticking to it! ■



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