Engineer

INNOVATION

Issue 6

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A year unlike any other

Siemens PLM Software

Jan Leuridan
Senior Vice President
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I don't think anyone will disagree with me when I say that 2020 has been a year unlike any other, and whilst we adjust to the 'new normal', life has gone on. Engineer Innovation crosses my desk once again and I am inspired by the contribution our customers continue to make to improve our future. I am also struck, as I read these articles, by the Simcenter ecosystem that has grown even bigger despite many of us being quite remote from each other.

There are two stories in this edition from our sister company, Siemens Energy, driving innovation in turbine technology to get more out with less input. Sounds so simple in those terms, it is incredibly satisfying to see Simcenter technology at the heart of those developments. That growing ecosystem stretches beyond our own company boundaries and I particularly enjoy seeing where our customers and partners are able to realize the power of simulation and test.

That power is showcased by NATRAX in India who are working to reduce noise pollution from vehicles, and the AZL Technology Center who use the Simcenter portfolio to design NVH test benches in turn supporting their customers to develop better autonomous vehicles. And so the ecosystem extends further.

The digital twin ecosystem is also evident in this issue, HP demonstrates how they are connecting simulation to additive manufacturing which would not have been possible previously. Also taking advantage of new technology are Salcomp, using electromagnetics simulation to improve their device charging products. You cannot access an ecosystem from a flat device!

And if like me you have had more time at home over the summer then you will also appreciate Briggs & Stratton using Simcenter to make your lawnmower more comfortable to push. Lastly if the weather permits, take a look at some tips on firing up the grill, there is some useful insight in our Geek Hub this issue.

Stay safe and stay connected. ■

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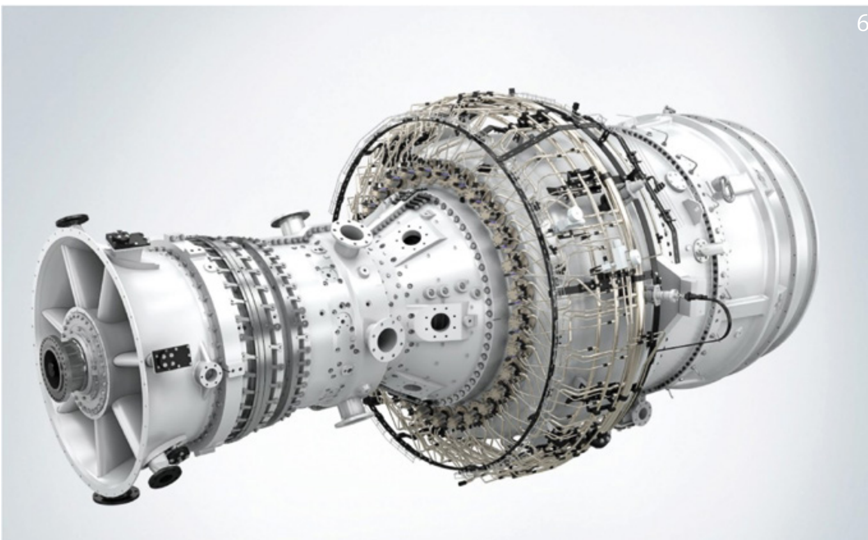


Engineer Innovation

Unlocking Innovation & lifecycle optimization

Regular Features

Today Meets Tomorrow:

Simcenter delivers a clean energy future

Every time you plug one of your many devices into a power socket, it's easy to pretend that the electrical energy that flows through the wires is somehow generated from a "clean power source" such as wind, hydro, solar or nuclear.

This is a complete fantasy. Across the world, less than a quarter of electricity comes from renewable sources (wind, hydro, solar and biomass). About a tenth comes from nuclear. More than two-thirds comes from the combustion of hydrocarbon fossil fuels (coal, natural gas and oil). Every kilowatt-hour of electricity that you consume comes at the cost of a puff of carbon-dioxide that will ultimately contribute to human-made climate change.

Not all hydrocarbons are equally "dirty" though. Thankfully oil is almost obsolete for large scale power generation (due to the economics of its fluctuating price), and natural gas is much cleaner than coal. In comparison with a brand-new coal-based power station, a modern natural gas turbine generates 50 to 60 percent less CO_2 per MWh of electricity generated. As we transition towards a clean-energy future, gas turbines play an essential role in providing a buffer between the intermittent green energy sources (solar and wind) and the "always-on" base-load sources (mainly nuclear and coal). Gas turbines are what keeps the power on when the sun isn't shining, and the wind isn't blowing.

But in the longer term that's not good enough. For gas turbines to feature in our zero-carbon future, manufacturers need to find ways to operate them robustly using carbon-free synthetic fuels such as ammonia and hydrogen.

In this issue of Engineering Innovation, we examine how Simcenter is being used at both ends of the gas turbine to bring about that transition. The first article, **"A Clean Energy Future"**, concentrates on the "hot" end of the gas turbine in which chemical energy is transformed by combustion into thermal energy. We explore the use of hi-fidelity simulation to understand and mitigate thermo-acoustic oscillations that can occur as a consequence of using non-conventional fuel mixtures, including those running completely on synthetic fuel.

Ultimately all thermal (coal, gas, oil or nuclear) power stations work by converting that thermal energy into rotational kinetic energy that is used to drive an electricity-producing generator. In our second article, **"Cooling a Full Scale Turbo Generator"**, we explore how Simcenter is helping to increase the reliability, efficiency of the electricity generation process, while at the same time reducing cost and maintenance overheads. Clean energy sources must be both dependable and affordable if they are going to replace the dirty power sources that currently fuel our economy.

Of course, none of this will really save our planet and our species, unless we can address the elephant in the room. Although gas turbines can be deployed to even out the fluctuations in the wind and solar supply, electricity grids still require an "always on" base capacity that is almost entirely provided by aging nuclear power stations, and carbon belching coal fired facilities. Unless we can rapidly bring new nuclear capacity online, the climate will continue to suffer the consequences of an over reliance on coal.

In our third article, **"Delivering Next-Generation Nuclear Reactors"** we visit the world's first Generation III+ nuclear power-plant, which has been designed with the aid of a comprehensive Simcenter digital twin. And then finally, we look at how Simcenter is being used from the earliest stages of the design of a new nuclear reactor in, **"Driving Digitalization in the Nuclear Industry".**

Figure 1: The Siemens SGT-800 Gas Turbine

A clean energy future

LES Simulations hold the key to cleaner fuel flexible gas turbines

By Stephen Ferguson, Siemens Digital Industries Software

Gas turbines play an increasingly critical role in delivering energy security, dynamically evening out the peaks and troughs in production from intermittent power sources such as wind, solar and hydroelectricity. However, efforts to reduce NOx emissions have the potential to introduce thermo-acoustic oscillations that can limit the range of operation of low-emissions gas turbines.

I spoke with Dr Daniel Moëll, a Combustion Engineer with Siemens Energy, who has been pioneering the use of CFD simulations with large Eddy simulation (LES) models for understanding and predicting the formation of thermo-acoustic waves in gas turbine combustors.

The changing role of gas turbines in a clean energy future

Although natural gas is obviously a fossil fuel, when compared with oil and coal, it releases much less carbon dioxide during combustion. In comparison with a brand-new coal-based power station, modern gas turbines generate 50 to 60 percent less CO_2 per MWh of electricity generated. The International Energy Agency estimates that coal-to-gas switching has saved over 500 million metric tons of CO_2 emissions in the past decade, which is equivalent to the savings that would have been generated by putting 200 million electric vehicles on the road during the same time period.

From an air pollution point of view, gas turbines are also running cleaner than ever. With the almost universal adoption of "lean premixed combustion" technology (in which the fuel is mixed with air to reduce the temperature of combustion), modern gas turbines routinely deliver so-called "single-digit" NOx emissions when operating at full load.

Despite all that has been accomplished in making gas turbine technology cleaner and more efficient, the industry is facing several key challenges that have arisen from the changing way in which the technology is being deployed. Originally designed for producing "base-load" electricity, operating continuously at full power, gas turbines are increasingly required to provide a more "dynamic-load" capability. With aging nuclear plants providing most of the steady-state base-load and increasing wind and solar capacity providing a fluctuating intermittent load, gas turbines are now necessary to even out the peaks and troughs between other power sources. Put simply, gas turbines are what keep the lights on when the sun isn't shining, and the wind isn't blowing.

While simple gas turbines are ideal for this role, they can be started up in minutes and ramped up and down quickly as load requirements change, the operating envelope of a modern "low NOx" gas turbine may be limited by thermo-acoustic oscillations.

Thermo-acoustic oscillations

While the overall thermodynamic efficiency of a gas turbine (or any engine) increases with the temperature of combustion, NOx formation also increases rapidly with combustion temperature. Since the 1980s, gas turbine manufacturers have been experimenting with dilution as a method of controlling combustion temperature (and therefore NOx formation). Although early attempts used so-called "Wet Low Emission" methods involving the injection of water or steam to control combustion temperatures, most gas turbines manufactured today employ Dry Low Emission (DLE) combustion systems, in which air is premixed with the combustion fuel so that combustion occurs in a lean-premixed regime. One of the key success factors when operating at DLE conditions is achieving enough mixing between fuel and air.

Although DLE systems are extremely efficient in reducing NOx formation, they do present additional engineering challenges, many of which are related to thermo-acoustic instabilities which are more prominent in premixed

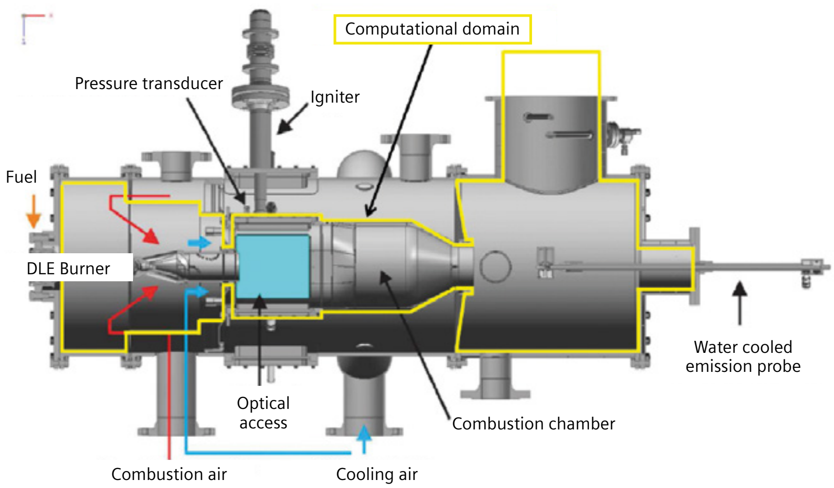


Figure 2: Experimental setup, showing extent of the computational model used for LES simulations

combustion systems operating close to the lean limit. Thermo-acoustic instabilities are highly undesirable oscillations that are generated by the interaction between the acoustic field and combustion processes.

"The most serious thermo-acoustic effects are a consequence of premixing. Older non-premixed systems are incredibly stable but have very high NOx emissions," explains Dr Moëll. "If the flame temperature becomes too low, the heat released is not high enough for the combustion to be stable, because it's a high-speed flow that we are trying to stabilize the flame in. This results in the stability issues."

These instabilities can significantly reduce combustor performance. If not properly controlled, the instabilities can cause self-sustained large amplitude oscillations that may cause additional wear and tear, or even catastrophic destruction if they happen to excite the natural frequencies of the turbine structure. All modern gas turbines are equipped with automatic safety control systems that prevent this from happening but shut-down of the turbine means loss of power generation, so needs to be avoided.

"The dangerous thing about thermo-acoustic instabilities is that they contain a huge amount of energy," said Dr Moëll. "For example, an SGT-800 generates 130MW of thermal power, so if you generate an instability, you have an almost infinite amount of power to drive it, operating at thousands of cycles per second. Uncontrolled they have the potential to cause lots of damage"

Although thermo-acoustic instabilities are well understood, and well managed in industrial gas turbines operating at close to full load, they can become more problematic under partial loads, or as we shall discuss later, for different mixes of fuels.

Large Eddy simulation
"Previously the only way of investigating dynamic thermo-acoustics effects was on an actual engine on a test-bed," said Dr Moëll. "You have to run the engine, measure the dynamics, stop the engine and then work out how you are going to damp out the oscillations and run again to see if the problem is fixed."

Not only is this "trial and error" approach time-consuming and expensive, but it also doesn't give much insight into the combustion instabilities that ultimately lead to the thermo-acoustic vibration. Dr Moëll and his colleagues turned to computational fluid dynamics (CFD) in order to improve their understanding of how these thermo-acoustic oscillations originate, aiming to damp them out in future generations of gas turbines.

Although CFD is used extensively in the design of gas turbine combustion systems, the majority of simulations use "Reynolds-averaged" (RANS) turbulence models. These model the overall influence of turbulence, instead of predicting the motion of individual turbulent eddies. While this approach works well for understanding most fluid dynamics, it cannot reasonably predict an inherently transient phenomena such as the thermo-acoustic behavior of a pre-mixed gas turbine combustor.

Instead Dr Moëll and his colleagues adopted a more fundamental approach to simulating turbulence, using Simcenter™ STAR-CCM+™. Large-eddy simulation (LES) is a transient technique in which the large scales of the turbulence are solved explicitly, and the small-scale motions are modeled. Whether a turbulent eddy is resolved or modeled depends on the local grid resolution, a consequence of which is that LES calculations require fine computational meshes, and small time-steps. In comparison to the stationary RANS methods (which model rather than resolve turbulence), LES is computationally very expensive, and until recently prohibitive at an industrial scale:

"The barrier until recently has been down to computational cost - these are expensive calculations," explained Dr Moëll "10 years ago, LES simulations were completely out of the question, it's only in the last 2-5 years that these types of calculations have become feasible on an industrial scale."

In a recent ASME paper entitled: "Large Eddy Simulation and Experimental Analysis of Combustion Dynamics in a Gas Turbine Burner" Dr Moëll and his colleagues validated an LES simulation of a gas turbine burner fitted to an atmospheric combustion rig. This burner, from the Siemens SGT-800 gas turbine, is a low NOx, partially premixed burner, where preheat air temperature, flame temperature, and pressure drop across the burner are identical to engine full load conditions. The simulation captured all the geometric detail present in the real combustion chamber, with a computational mesh of

"…the simulations revealed the mechanisms behind the pressure fluctuations we observed on the rig,"

Dr Daniel Moëll
Combustion engineer with Siemens Energy

28 million cells, most of which are distributed in the swirler, mixing and reaction regions. The cell size in the flame region and most of the mixing region was less than one millimeter.

When compared with experimental observations on the same rig the LES results showed good agreement, and predicted the principle mechanisms that ultimately are the cause of thermo-acoustic oscillations:

“The LES predictions show good overall agreement with experimental data in terms of the mean flame structure and pressure fluctuations that are produced. More than this, the simulations revealed the mechanisms behind the pressure fluctuations we observed on the rig,” said Dr Moëll. “Axial movements of the flame are coupled with the pressure drop across the burner and the local swirl number, acting as a force/feedback loop between velocity, pressure, and local flame position. The axial flame pulsating is interacting with an acoustic mode generating axial pressure fluctuations in the combustion chamber.”

“In addition to the two dominant axial pressure fluctuation modes, a mode acting in the cross direction of the combustion chamber is discovered,” continued Dr Moëll. “This pressure wave is bouncing between two of the four combustion chamber walls and is triggered by the general flame movements”

Once validated, the Simcenter STAR-CCM+ simulations provided a wealth of insight and engineering data:

“The real value of CFD is to explain the dynamic effects because we have all of the necessary data in the flow field. Once you have demonstrated the CFD result matches the experiment, you can go into much more detail in investigating flow phenomena through post-processing and data analysis,” said Dr Moëll. You can look at the detailed coupling between vortex structures, heat release, and acoustics. You can then start to answer the important questions: ‘how can I change the flow field to improve the dynamic performance of my gas turbine, with fewer emissions and more stability?”

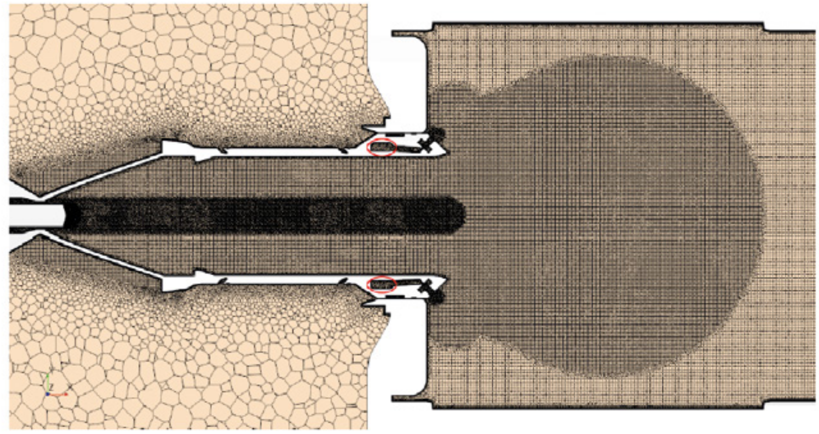


Figure 3: Computational mesh used for LES simulations

Beyond fossil fuels

Although natural gas (principally methane) is by far the most commonly used fuel for gas turbines, attention is increasingly turning to synthetically generated non-fossil fuel gases, such as hydrogen and ammonia. These can be mixed with methane in order to further reduce CO_2 emissions. However, changing fuel mixes is another potential cause of thermo-acoustic instability, something else that LES simulations can enhance insight into:

“Understanding this coupling between fuel and transient flow effects is of key importance to gas turbine developers,” said Dr Moëll. “On a global level, using different fuels results in different flame shapes and different flame positions - which is one of the things that we can easily simulate using CFD, but it is very difficult to measure on a test-rig. We can also predict changes in dynamic response that will alter the thermo-acoustic behavior of the system by using a different fuel, where the heat release is slightly different.”

The possibilities are endless here – for example another way of dealing with the intermittent nature of wind could be to use excess wind-power to manufacture hydrogen which could be used as pure fuel for electricity producing gas turbines that run at night, without CO_2 emission. Of course, the different chemical properties of a hydrogen flame might then lead a changed combustion behavior, which also need to be mitigated using LES CFD simulations.

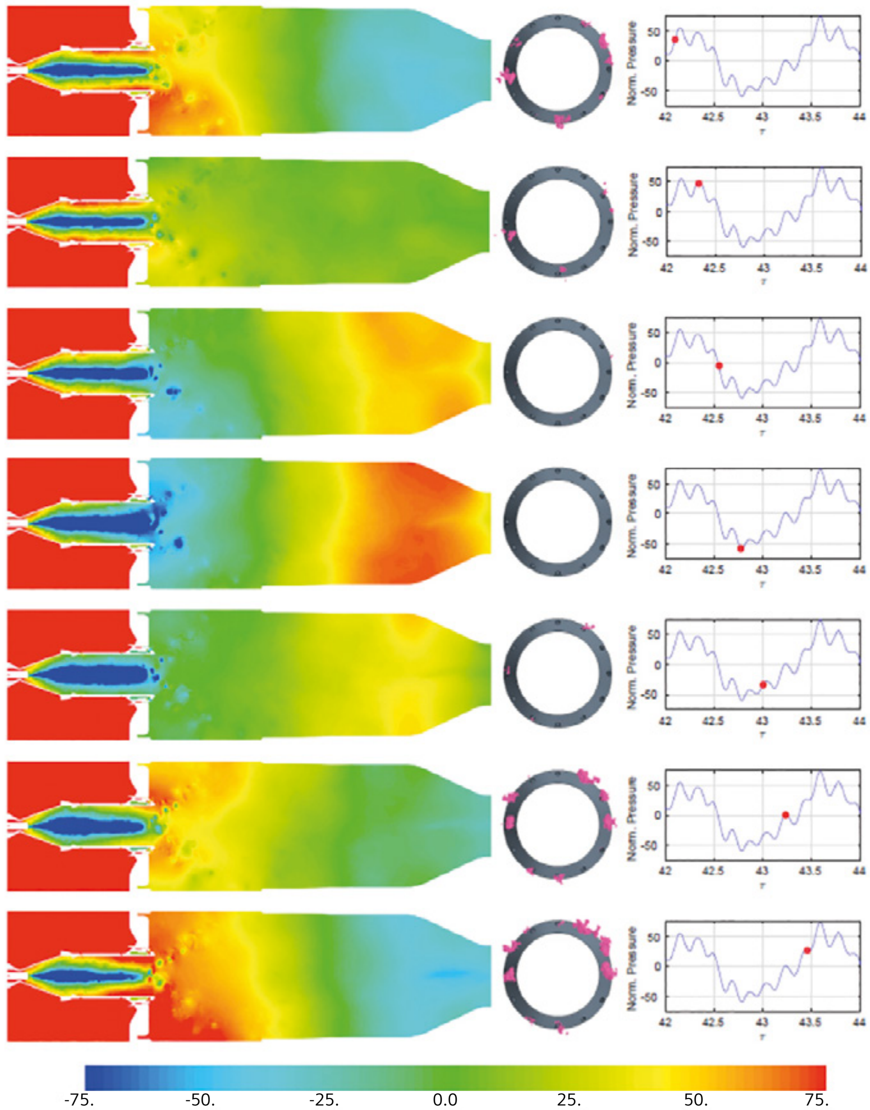


Figure 4: LES simulations of pure methane combustion

"Greater insight leads to increased innovation."

Dr Daniel Moëll
Combustion engineer with Siemens Energy

"This is where CFD is really useful - you can try running an actual gas turbine on a different fuel but evaluating the downstream impacts on the entire gas turbine system is very difficult," he said

Greater insight leads to increased innovation

"Our study shows that LES has a good potential to capture complex flow/flame/acoustic interactions in real gas turbine geometries," explains Dr Moëll. "This has two strong benefits. First, detailed information regarding flame stabilization and its impact on the thermo-acoustics may be provided, which is of great assistance for gas turbine developers"

Having successfully demonstrated the ability of Simcenter STAR-CCM+ in predicting thermo-acoustic oscillations, Dr Moëll is confident that this type of simulation can eventually be routinely deployed in the design of future generations of gas turbine:

"Greater insight leads to increased innovation. CFD will allow us to simulate new burner geometries or new combustion chambers that might offer improved performance," he concludes. "The risk is always that if you introduce a new burner or a new combustion chamber, that you might introduce different combustion dynamics. CFD is a useful pre-screening method for new technology and a useful explaining method: so, if something does introduce new combustion dynamics, we can explain why, and then make appropriate design changes in response."

References

"Large Eddy Simulation and Experimental Analysis of Combustion Dynamics in a Gas Turbine Burner", Daniel Moëll, Andreas Lantz, Karl Bengtson, Daniel Lörstad, Annika Lindholm, Xue-Song Bai, J. Eng. Gas Turbines Power. Jul 2019, GTP-18-1448, https://doi.org/10.1115/1.4042473 ■

Nitrogen dioxide or NOx is a compound formed from nitrogen and oxygen as a result of the high temperatures generated during combustion processes.

NOx is composed of oxygen and nitrogen, so the air entering the engine, consisting of 21 percent oxygen and 79 percent nitrogen, contains all the ingredients necessary to produce this pollutant. The only additional factor that is required is a temperature high enough to cause oxygen and nitrogen to combine. Although NOx can be created naturally, the vast majority of global NOx production is a consequence of combustion, from energy production and transportation

NOx reacts with ammonia, moisture, and other compounds to form nitric acid vapor, which damages lung tissue and has a deleterious effect on breathing and respiration. NOx is also a key component of acid rain that has an environmental impact on forests and lakes. It also contributes to the formation of fine particles and ground-level ozone, both of which are associated with adverse health effects.

Since the introduction of emission standards for gas turbines in the late 1970s, gas turbine manufacturers have implemented a variety of innovative solutions that both reduce the pollutants created during the combustion process and increase the amount removed through aftertreatment of exhaust gases. These measures have been highly successful in reducing the emission of harmful pollutants, particularly

In the early 1980s, industrial gas turbines were routinely emitting 75ppm NOx. Today regulations in most countries require that emissions are limited to 25 ppm or less, and increasingly in Europe and the US even stricter NOx emission standards require maximum levels of 15 or even 10 ppm. In response to this, manufacturers such as Siemens Energy had largely achieved so-called “single-digit” NOx emissions in the latest generations of gas turbines (< 10 ppm).

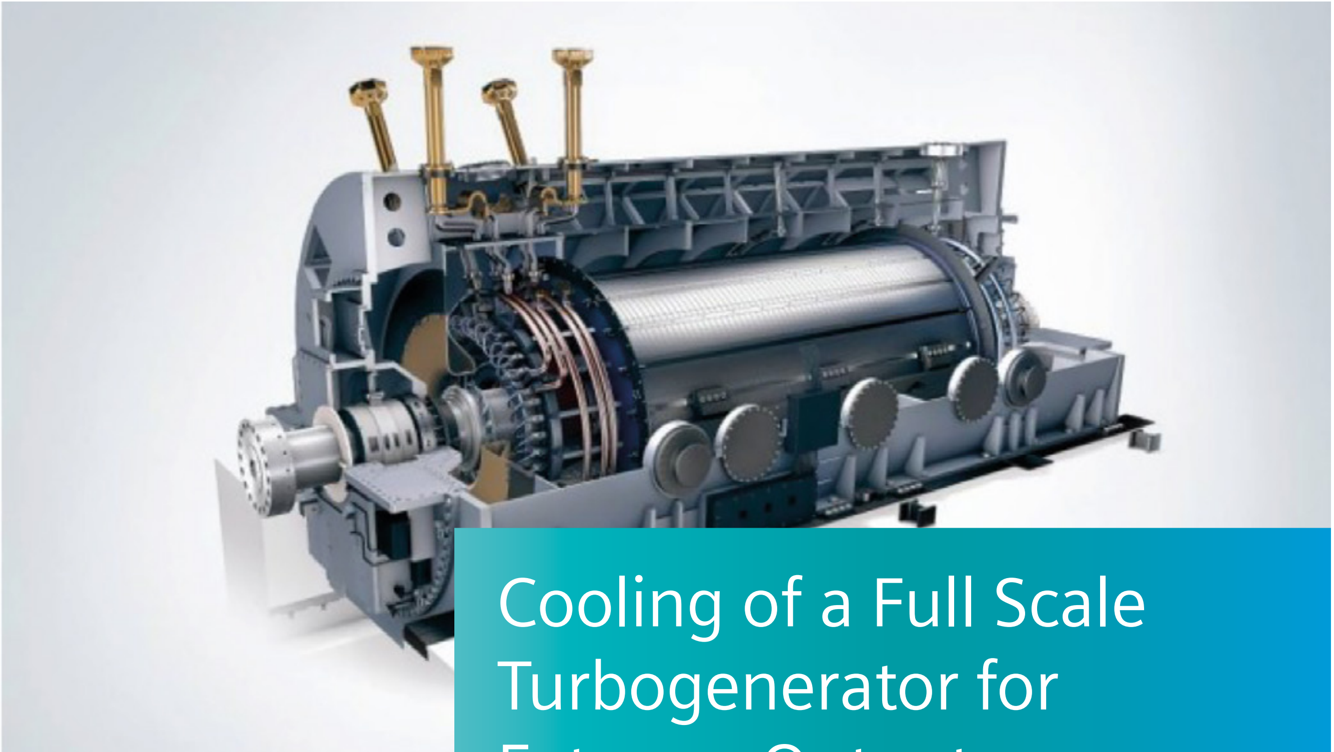


Figure 1: The new SGen-3000W series

Cooling of a Full Scale Turbogenerator for Extreme Outputs

By Dr. Christian Jäkel, Development Engineer, Siemens Energy

Siemens generators are the perfect solution wherever power has to be generated quickly, reliably and efficiently – whether on board of a ship or oil platform, in an industrial plant, a large gas or steam power plant or for synchronous condenser application to help integration of renewables. The latest water/hydrogen cooled generators for power plant application high power output benefit from proven design and technologies as well as the application of a building-block approach.

The new SGen-3000W series shares many features with other products across the Siemens portfolio which allows for optimized material selection and performance to provide customers with low-cost, highly efficient, and easily maintained generators for high-power applications.

One challenge faced by the engineers designing the SGen-3000W series was the cooling concept of gas cooled generators. The proven, long-established and reliable design process includes, among other things, the analysis of four distinct areas: the cooler, stator, blower and rotor. (Figure 2).

Simulating the cooling of the entire generator, including all four sections, would be immensely beneficial but requires a substantial effort that was not deemed worthwhile. The investigation of individual sections of the complex geometry led to uncertainties with their interconnection points as transfer boundary conditions are needed Alternatively a reduction to a single 1D model would help a quick solution but lead to a reduction of geometrical resolution, which is not ideal as at this stage of development. Details of the geometry have to be taken into account to validate 1D simulation parameters first. Accordingly some iteration between CFD and 1D analysis is required which consumes a lot of effort and resources.

Dr. Christian Jäkel is responsible for fluid dynamics, heat transfer and the cooling

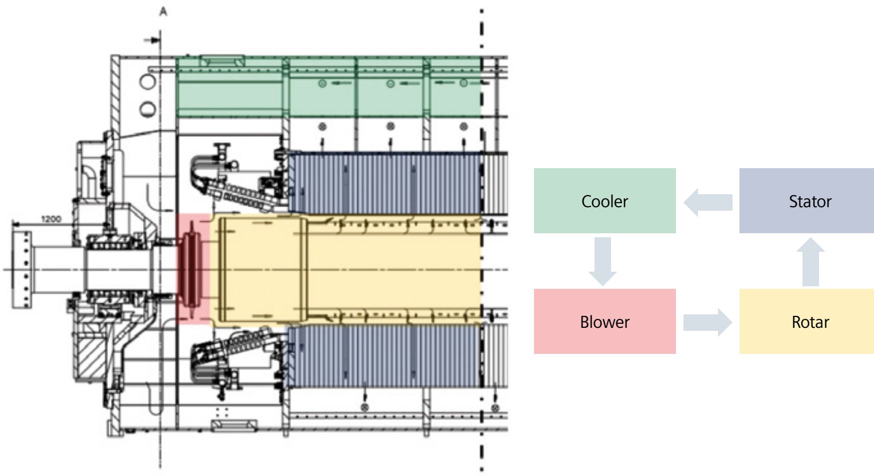


Figure 2: Design process cooling concept

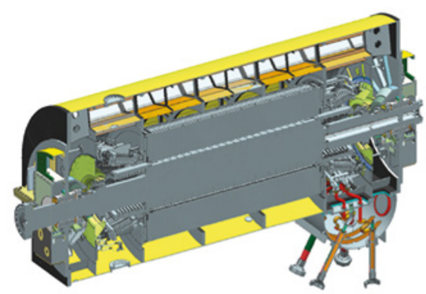
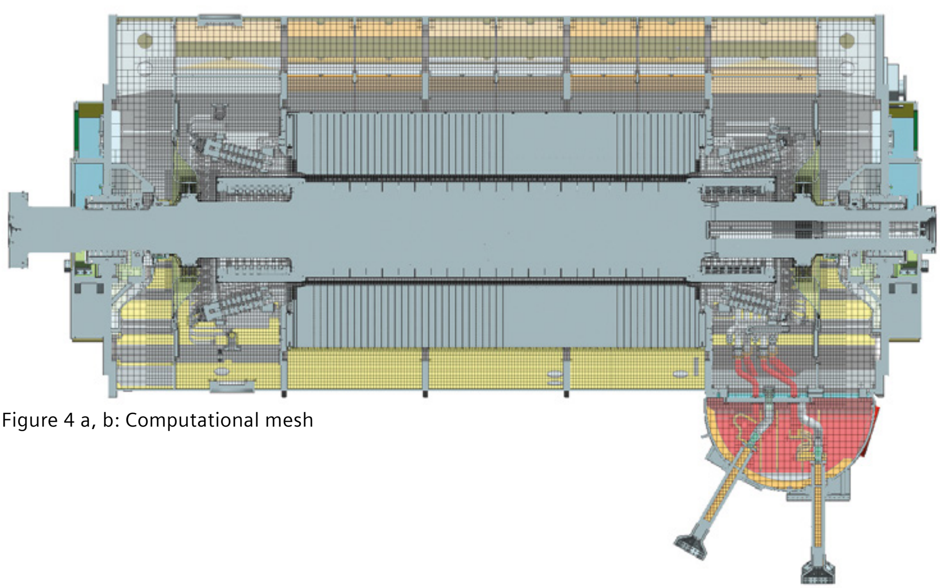


Figure 3: SGen-3000 W series CAD section view



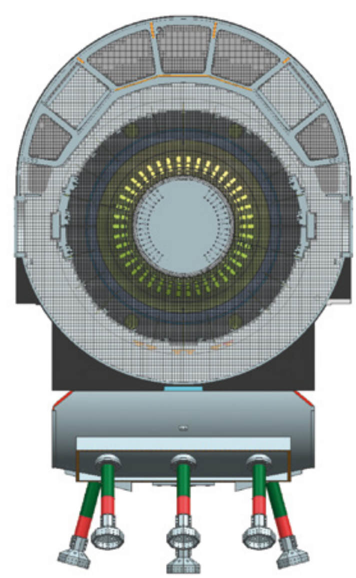


Figure 4 a, b: Computational mesh

concept of turbo generators. He possesses a wealth of knowledge and experience in the design and realization of generators and gas turbines and explains: "A lot of optimization we thought about cannot be done because the effort exceeds the benefits."

Typical rotors have a diameter of about 1.2 meters (m), while the stator length is 5 m with a power output of up to 850 Megavolt Amperes (MVA). The smallest gap design for the cooling circuit in the rotor is 2 millimeters (mm) and 5 mm in the stator, resulting in a geometrical ratio of 2:5000, which can be problematic for simulations.

In an effort to improve the simulation process, Dr. Jäkel was introduced to Simcenter™ FLOEFD™ software. The first test was to import a full native, highly complex Siemens NX CAD model from Siemens Teamcenter® and to review the total amount of manpower that was to be invested to prepare, set up and finally analyze such a complex CAD model. One of the objectives was to investigate the global pressure and flow distribution within the complete model, including the rotor, the heat exchanger as well as all small cooling channels. As the geometry will also be used for manufacturing, it is one of the most intricate models as it includes a few thousand parts with no simplifications.

Naturally, unused and unnecessary components were disabled for the simulation. One of the objectives of this software stress-test was to investigate the required total efforts to run such an extraordinarily complex model.

Figure 5: Test bench and measurement sensors

Since the complete manufacturing model from Teamcenter was used, a few geometrical preparations were necessary, for example closing gaps for welding seams and screw holes to ensure an appropriate simulation model was achieved. The manual efforts for defining the physical simulation model and mesh took about two man-days in total. In Simcenter FLOEFD all boundary conditions are applied to the CAD geometry directly which enables a very short graphical user interface (GUI) interaction time for the user. Local refinement of the mesh was only applied in particular local regions such as small gaps and areas of high gradients to further reduce the overall computational efforts for the user. The final computational mesh consisted of 14.5 million cells. Simcenter FLOEFD's SmartCells, a feature that introduces a multi control volume approach with a combination of fluid and solid volume in one cell with a resolution of the fluid/solid boundary allows for an effective, automated meshing of complex CAD geometries with minimal user input. The automated mesh generation, including the fluid volume detection, was completed in eight hours on a regular computer-aided design (CAD) workstation. (Figure 3 a, b). Solving this problem took around four days of computational efforts and included six rotor revolutions in transient mode with "sliding" rotation physical model.

For the very first time in their practice of simulating full scale turbogenerators, Siemens simulation engineers were able to review the full simulation results of the whole complex machine including all sections. This would usually be achieved with the necessity of extremely simplifying CAD and simulation models with a significant number of implied assumptions and the resulting CFD simulation would be unreliable.

Further improvements could include an acceleration of the CAD preparation, mostly from a designer's perspective. Furthermore, more specific areas of interest could be analyzed, such as the gas outlet area.

Subsequently, a detailed validation of the results was carried out with aid of Siemens' remarkable test bed, where real machine data was obtained through physical tests.

The measurements included more than 30 kiel probes, 40 static pressure probes, 40 temperature sensors, and 12 specially customized seven-hole probes. Some of these sensors were

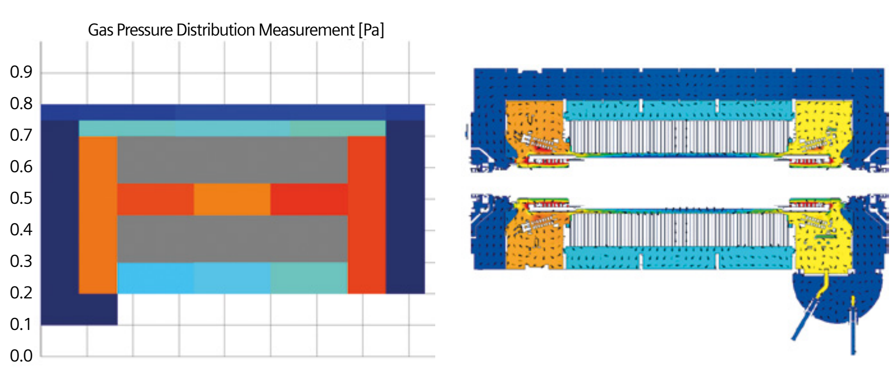


Figure 6: Static pressure measurement and simulation

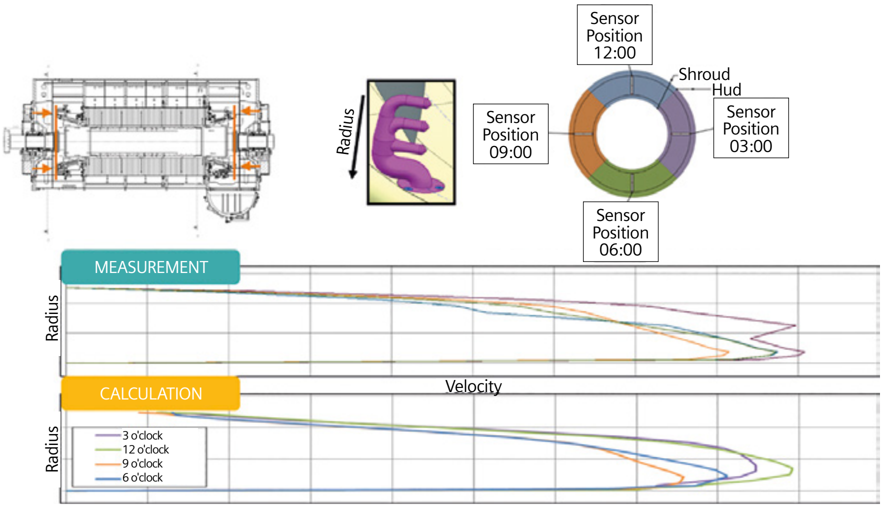


Figure 7: Blower I, velocity distribution

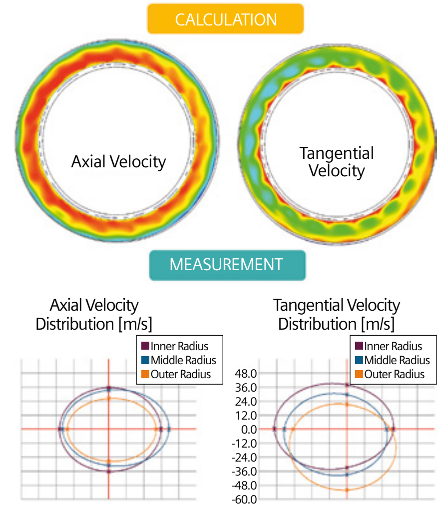


Figure 8

manufactured using additive manufacturing processes, to ensure perfect integration and to meet some additional requirements of a high voltage environment. (Figure 4)

Many comparisons between measurement and simulation were carried out, some of which are discussed in this article.

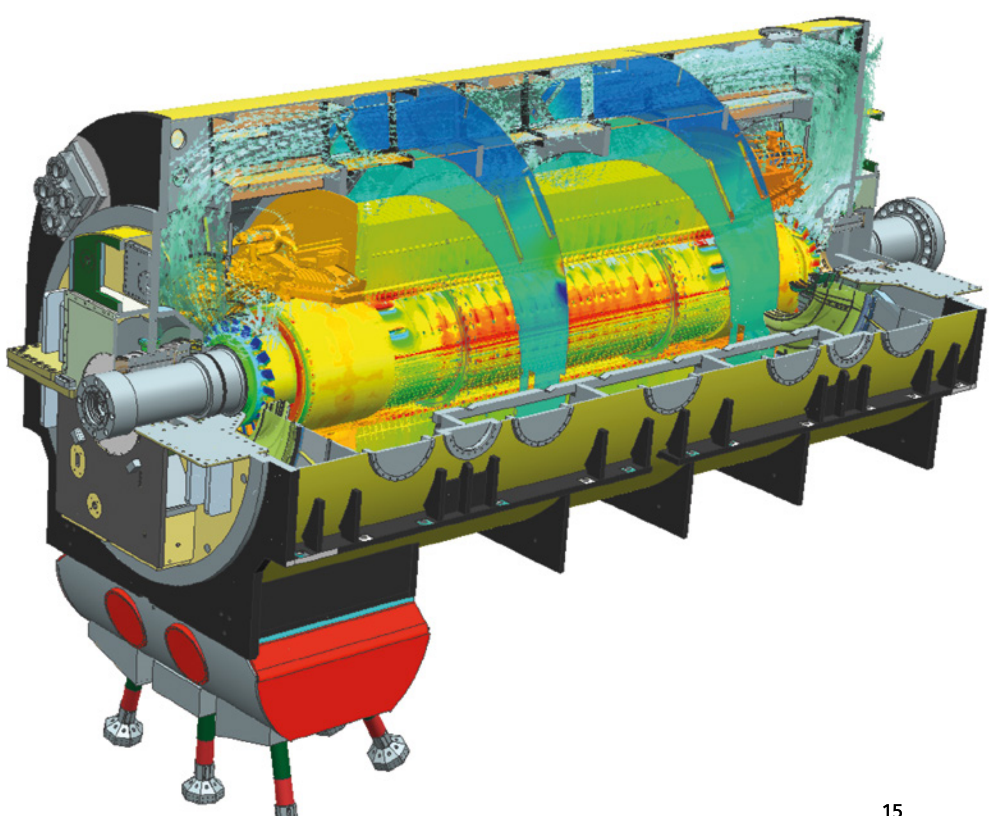
The static pressure results achieved a deviation of less than 15 percent between simulation and measurement, which is more than acceptable when considering the whole device in one simulation (Figure 5). In contrary, a consecutive numerical analysis with separated domains of non-validated geometry is deemed to yield increased deviation.

The comparison of the velocities of the blower showed a very good agreement with physical tests. (Figure 6)

The simulated circumferential velocity distribution due to unsymmetrical flow path is quite similar, with an overall volume flow of only two percent lower than measurements which is a great achievement of the simulation approach.

This project, for the new Siemens SGen-3000W series has proven that model complexity can be handled by Simcenter FLOEFD in NX. The pressure and volume flow show reasonable distribution and order of magnitude, meaning that Simcenter FLOEFD is capable of calculating a whole closed-loop machine cooling system with an accuracy of 2 percent for the simulated fan flow rate and within experimental uncertainties.

In the past the benefit for an entire simulation did not justify the effort but by using Simcenter FLOEFD, the overall benefits outweigh the efforts and enables the reduction of lead and calculation time from several months to a few weeks. It was a significant step forward to be able to simulate this model complexity in its entirety, leading to most competitive product designs. ■



OKB GIDROPRESS

OKB GIDROPRESS uses Simcenter STAR-CCM+ to deliver next-generation nuclear reactors

In 1997, the global climate treaty known as the Kyoto Protocol was signed in Kyoto, Japan. This treaty symbolized the fact that the world had finally "warmed up" to the threat of global warming. Countries unanimously pledged to reduce carbon dioxide (CO_2) emissions and greenhouse gases in the atmosphere. Coal, the major energy source of CO_2 emissions, contributed 25 percent of global energy consumption. Something had to change.

But change was painstakingly slow. In 2017, coal made up 27.6 percent of global energy consumption. Renewables were making progress, but the earth was warming up faster than before.

That same year, the world's first full startup of a Generation III+ nuclear reactor, the VVER-1200, a water-moderated, water-cooled reactor, happened in Novovoronezh in Central Russia.

There is a connection here: the still-persistent reliance on coal and fossil fuels today is a pressing problem. The VVER-1200 is a small yet significant part of the solution.

The nuclear option

To combat the growing threat of climate change, the International Energy Agency (IEA) has estimated that by 2040, 84 percent of all energy must come from low-carbon sources. This marks a significant jump from the current value of 35 percent and one that cannot be met by renewables alone. To tackle the looming climate change threat, the scientific community agrees an energy plan inclusive of all carbon-free sources is needed.

Enter the nuclear option. Nuclear energy is still the best available source of continuous, carbon-free electricity and can play a significant role in meeting

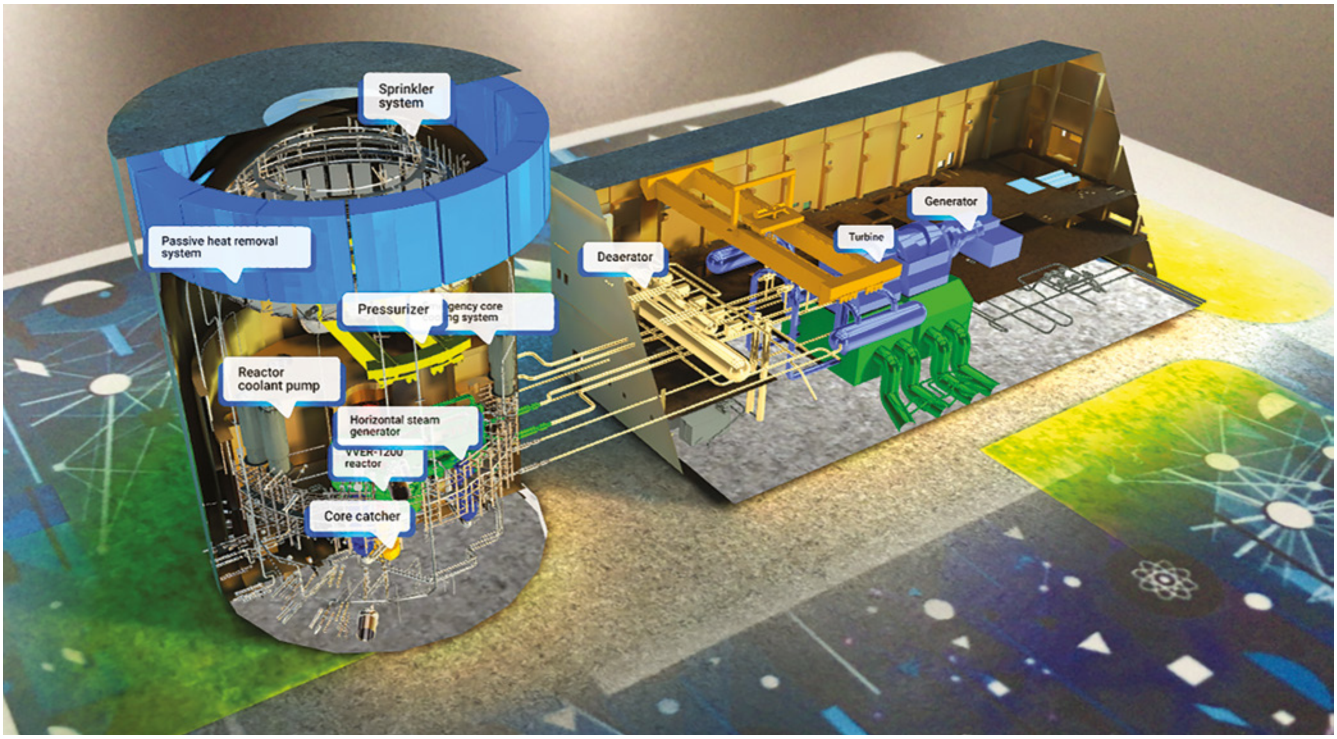


Figure 1: A VVER-1200 nuclear power plant design shown in augmented reality.

these aggressive energy targets. To produce one kilowatt hour (KWh) of electricity, the emissions from nuclear power is 40 times less than burning coal for the same amount of electricity. Nuclear energy is also the safest energy source per terawatt hour (TWh) and the most environmentally friendly, contributing the same amount of emissions as offshore wind energy and significantly less than hydro and solar power.

But the nuclear industry is at a crossroads. Most of the current reactors are reaching the end of their 40-year lifecycle and are not economical to operate. More importantly, their safety systems are not up to post-Fukushima standards. Newer technology like small modular reactors (SMR) are incredibly promising but unproven, unlicensed and not yet under construction.

This is where the role of Generation-III+ reactors like the VVER-1200 is amplified in the fight against climate change. Designed with some of the most sophisticated engineering simulation in any industry, the VVER-1200 is a ready answer to the immediate threat of climate change and can help meet the world's carbon-free energy requirements.

"We do CFD simulations with Simcenter STAR-CCM+ to make the reactors better, cheaper and safer."

Vasilii Volkov
Design Engineer
OKB GIDROPRESS

Today, VVER-1200 reactors are operating or under construction in a handful of countries, primed to play an important role in lowering emissions. Better, safer and more economical than Generation III reactors, the Generation III+ reactor comes at a significant time for the nuclear industry.

The VVER-1200 reactor

The VVER-1200, a thermal neutron reactor, is the latest reactor from OKB GIDROPRESS, the Russian state nuclear agency with 70 years of experience in operating and constructing nuclear plants. An update from the popular VVER-1000 design, VVER-1200 reactors address the two main factors hampering nuclear adoption today: safety and economics.

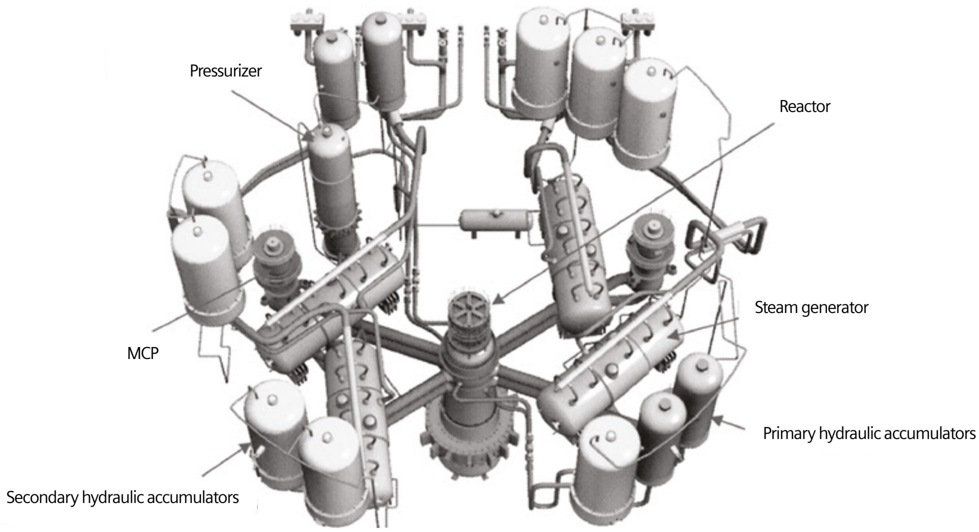


Figure 2: Layout of the primary circuit equipment in VVER-1200.

"Previously, it took us half a year to build a mesh. Now with Simcenter STAR-CCM+, the whole process takes about a week to mesh and analyze."

Vasilii Volkov
Design Engineer
OKB GIDROPRESS

The world's first Generation III+ reactor, the VVER-1200 is a specialized design of the pressurized water reactors (PWR) and provides improved performance and cost efficiency. Boasting a 20 percent higher power capacity, a 60 year service life, 18 month refueling cycle, complete factory manufacturing and 30 to 40 percent less personnel due to automation, VVER-1200 reactors lead to better economics.

But where the reactor really shines is where it really should: safety. The VVER reactor family is already known for their safety with 1,000 reactor years of fail-safe operation. The new VVER-1200 designs are equipped with an extensive combination of active and passive safety systems designed to meet all post-Fukushima safety requirements from the International Atomic Energy Agency (IAEA). The possibility of an emergency failure of a VVER-1200 reactor is about one per few thousand years.

State-of-the-art reactor safety

The VVER-1200 reactors can withstand the worst of natural disasters, including earthquakes greater than intensity eight on the Medvedev-Sponheuer-Karnik (MSK-64) scale, aircraft impacts, flooding and tornadoes. The state-of-the-art safety systems are designed on a "defense-in-depth" concept, providing multiple barriers and isolation systems to confine fission products in case of an accident and minimize damage.

Passive heat removal is the key to this improved safety. The reactors do not depend on external power for the critical safety systems, ensuring protection against a complete blackout. A core catcher under the reactor protects against core meltdown. Double containment with a ventilated gap protects against accidental radioactive release to the environment. All these systems exist in addition to the active safety systems, providing four trains of safety systems. The safety systems offer guaranteed protection delivering termination of nuclear reaction, continuous heat removal and containment of nuclear reaction.

Safety and economy in reactor design with simulation

Think of how difficult it is to inspect and test a nuclear reactor in the design stage:

the magnitude of the reactor, the components, the operation, and the fission. Once sealed, it is impossible to test and measure the internal operating performance.

With years of extensive reactor design experience, OKB GIDROPRESS knew their best chance to successfully design a new reactor system with improved safety and cost economics relied on a comprehensive digital twin – a "virtual reactor model." The manufacturer had an established simulation process built in Simcenter STAR-CCM+ software, the computational fluid dynamics (CFD) tool from Siemens Digital Industries Software. The virtual reactor model enabled the engineers at OKB GIDROPRESS to efficiently and accurately model the performance of all aspects of the nuclear reactor's operation.

The simulations helped the engineers at OKB GIDROPRESS guarantee extreme fuel reliability, higher availability and improved performance. The result is a modern reactor that is safe and economical.

Safest reactor; largest simulation
The world's first Generation III+ nuclear reactor was born together with one of the world's largest engineering simulation models, created in Simcenter STAR-CCM+.

Vasilii Volkov, design engineer at OKB GIDROPRESS, is one of the chief architects of the simulations behind the VVER-1200. "We do CFD simulations with Simcenter STAR-CCM+ to make the reactors better, cheaper and safer," says Volkov. "The simulations help us optimize the thermohy-draulic behavior, understand failures and design faster."

Volkov's team has used Simcenter STAR-CCM+ for years. For the VVER-1200, OKB GIDROPRESS pushed the code to its limits, modeling different equipment in the reactor. The most important simulation is modeling the first primary circuit of the reactor. The primary circuit is incredibly complex and provides the first line of cooling for the reactor core using water to transfer all heat from the core. The integrity of the primary circuit performance is the most critical aspect of reactor design, one which would be impossible without simulation.

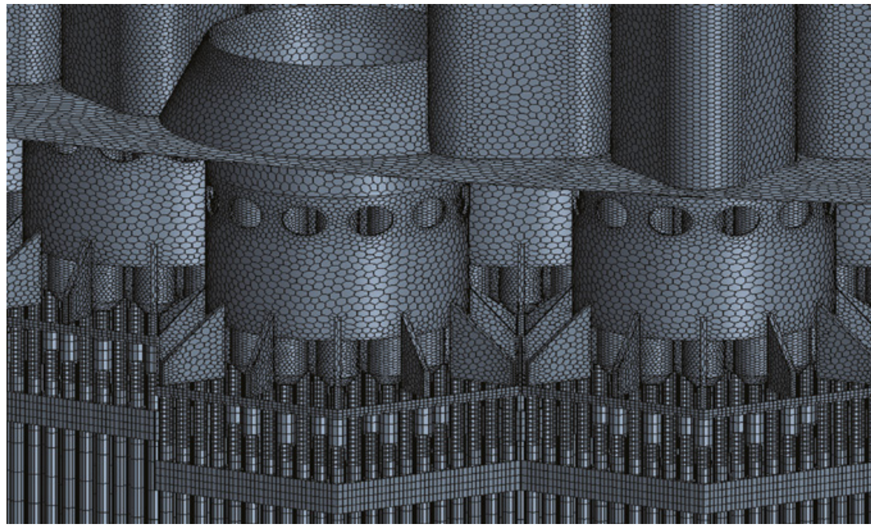


Figure 3: Details of the one billion cell computational mesh generated for CFD simulations in Simcenter STAR-CCM+.

To accurately assess the primary circuit performance, OKB GIDROPRESS developed one of the industry's largest CFD simulation models. The model included every component of the primary circuit in detail and is the only model in the world to include the real profile of the pumps and the wheel rotation. Approximations and simplifications were kept to a bare minimum. Capturing the reactor geometry accurately for simulation was crucial. The geometry preparation and meshing tools in Simcenter STAR-CCM+ proved more than capable. The incredibly high-fidelity reactor's comprehensive digital twin clocked in just shy of one billion computational cells and included multiphysics simulation of every aspect of the primary circuit.

"Simcenter STAR-CCM+ is the only CFD code that allows us to create simulations with a mesh size of one billion cells with ease and accuracy," says Volkov. "Previously, it took us half a year to build a mesh. Now with Simcenter STAR-CCM+, the whole process takes about a week to mesh and analyze."

The unsteady simulations of the primary circuit showed good agreement with experimental and measured data and significantly reduced the design time for the primary circuit. The steam generator was created based on previous designs, confirmed and improved with CFD simulations.

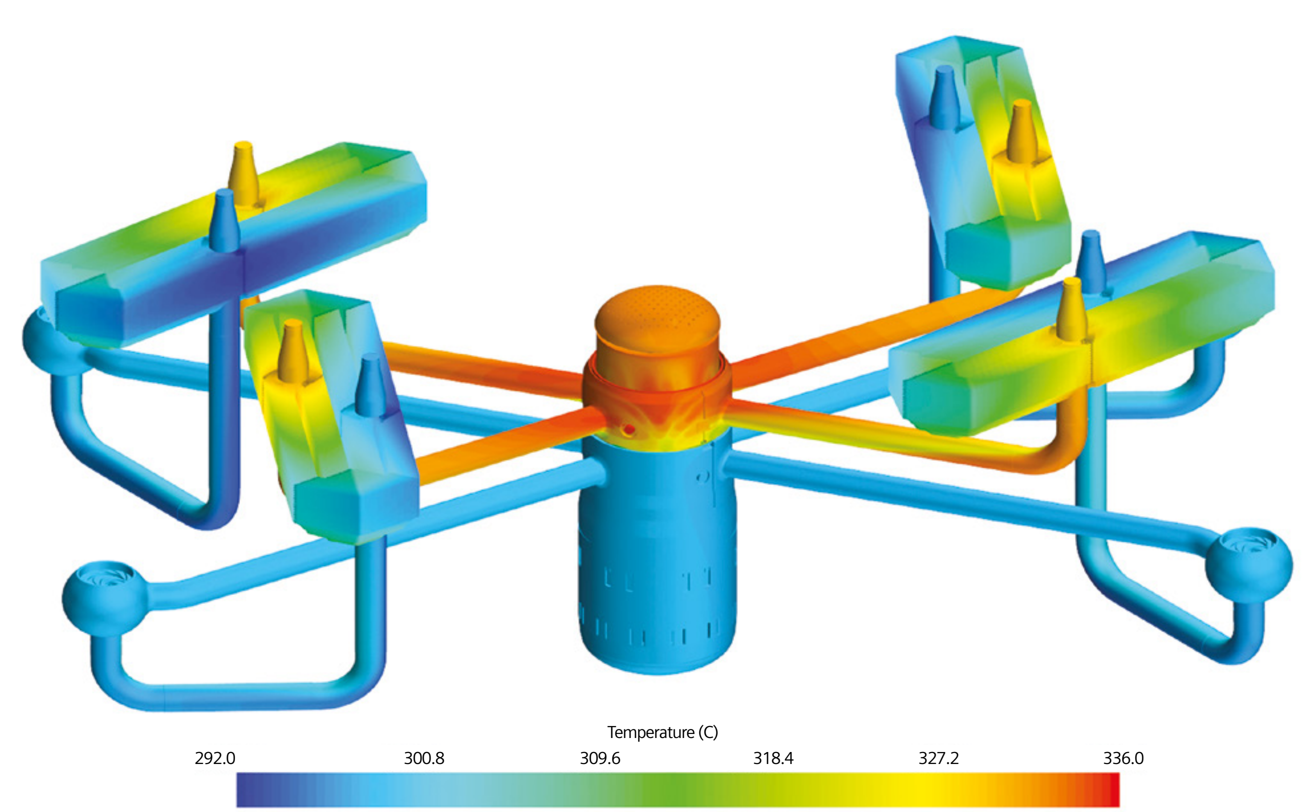


Figure 4: Temperature distribution on primary circuit components from Simcenter STAR-CCM+ simulations.

The reactor's comprehensive digital twin helped OKB GIDROPRESS to virtually analyze the full performance of the primary circuit. Pressure, temperature and flow of the coolant, mixing efficiency, impact of pumps and steam generator were all confirmed. In addition, simulations also provided performance insights and areas of improvement that would not have been available from experimental data. The ability to virtually visualize and analyze every aspect of the primary circuit performance in detail helped accelerate the reactor design and delivered the safest Generation III+ reactor on the market.

Managing the comprehensive digital twin with Teamcenter

With hundreds of components and personnel working together on a complex reactor design, it was crucial to streamline and manage the process every step of the way to design faster. To deliver on this, OKB GIDROPRESS used Teamcenter® software from Siemens for product lifecycle management (PLM) at every design step. Everything from design to test, 2D sketches to 3D models, and simulations to experiments were managed with a central platform in Teamcenter, allowing information to flow smoothly between different stages of product design. To meet the challenge of better reactor economics, shortening the design cycle plays a key role and the combination of Simcenter and Teamcenter provided OKB GIDROPRESS with the tools to achieve this. Simcenter and Teamcenter are a part of Xcelerator, a comprehensive and integrated portfolio of software and services from Siemens.

Designing the energy future

The design, construction and commissioning of a new reactor requires extensive digital simulation, both to accelerate the lengthy design process and demonstrate its safety and economic viability. Simulation also helps speed up the lengthy licensing process. Using simulation, OKB GIDROPRESS has delivered the immediate future of nuclear energy with their VVER-1200 reactors.

Extending the VVER-1200 design, OKB GIDROPRESS have also introduced the

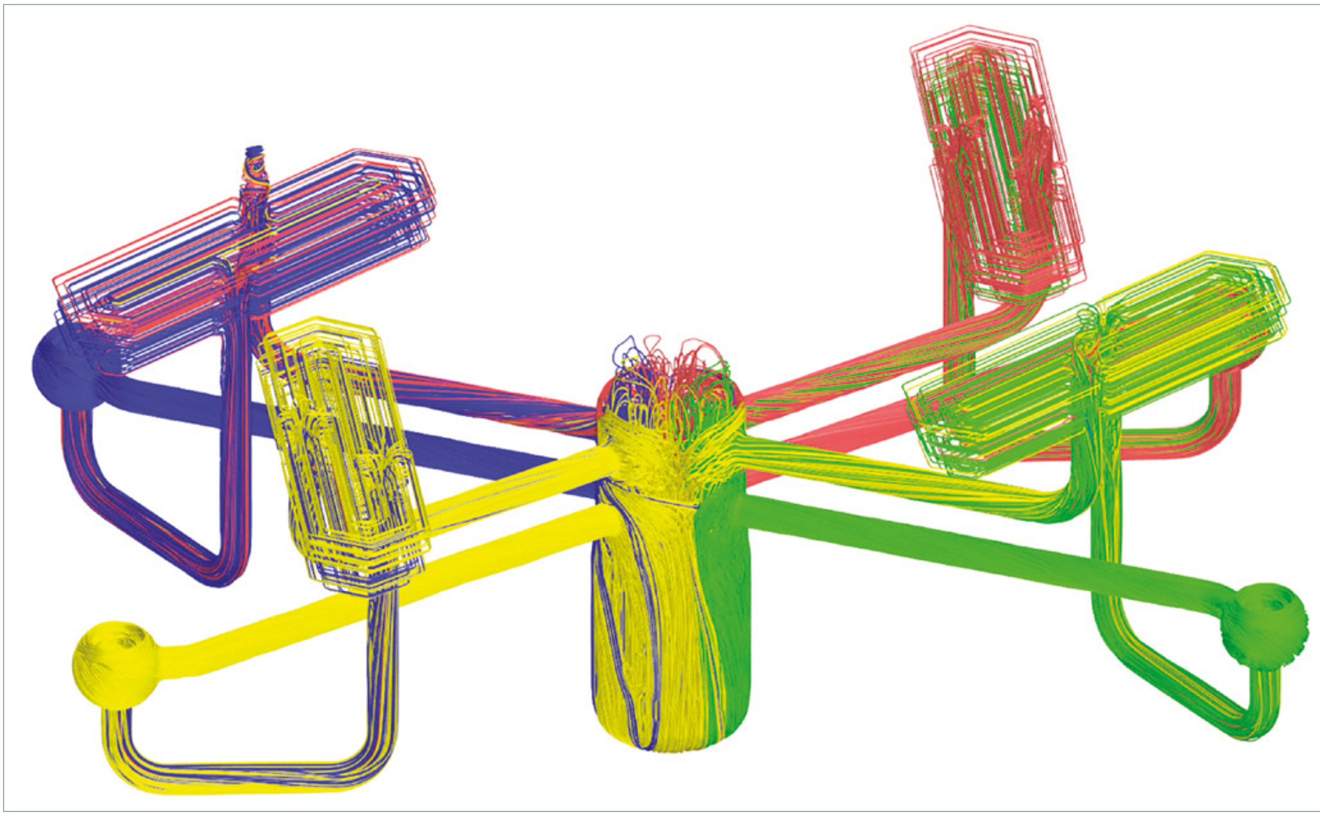


Figure 5: Flow streamlines from CFD simulations showing loop mixing helped OKB GIDROPRESS optimize coolant mixing performance.

VVER-TOI (typical optimized with enhanced information) design with the first plant in construction in Russia. Designed with the same simulation process in Simcenter, the VVER-TOI delivers increased power and cooling reliability, lower construction and operating costs, a 72 hour grace period for passive safety systems and 40 month construction time. Together, the VVER-1200 and VVER-TOI are helping reduce CO_2 emissions and deliver on our energy future.

"For the last 10 years, CFD simulations have helped OKB GIDROPRESS develop new equipment and maintain our leadership in the nuclear industry," says Volkov. "With Simcenter and Teamcenter, we can make better, more efficient reactors faster." ■

"Simcenter STAR-CCM+ is the only CFD code that allows us to create simulations with a mesh size of one billion cells with ease and accuracy."

Vasilii Volkov
Design Engineer
OKB GIDROPRESS

Digitalization in the nuclear industry

Figure 1: Traditional modeling approach where CAD and CAE are often disconnected

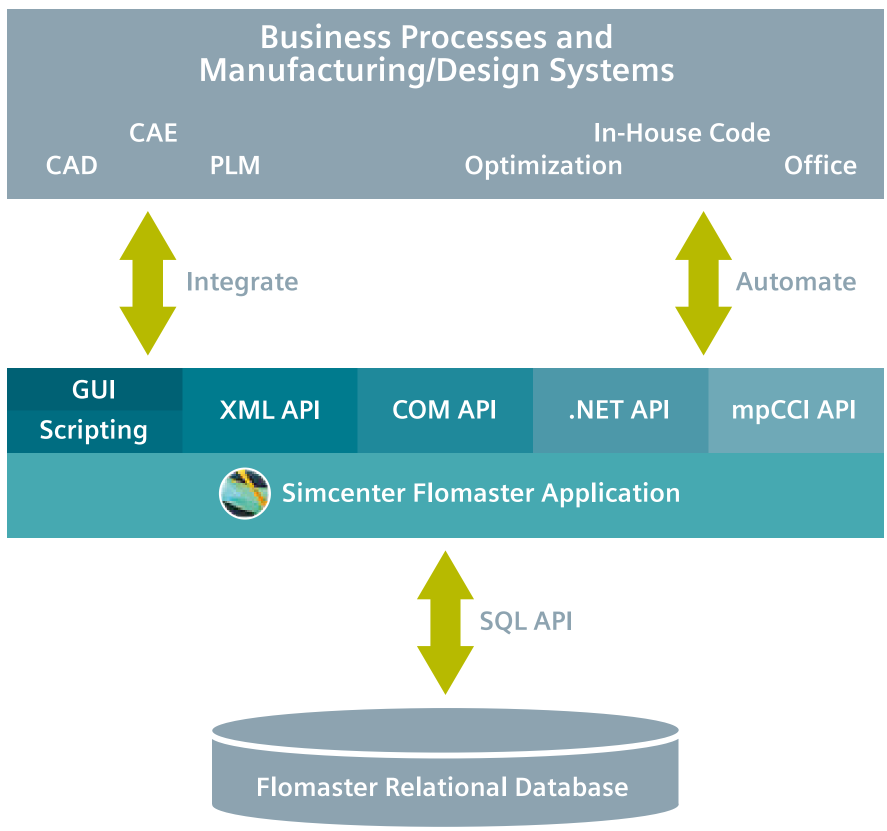


Figure 2: New approach integrating simulation and analysis with design

Digitalization poses significant opportunities to improve technical and business processes for most industries working with large and complex piping systems. Although new technologies are being introduced at a rapid pace, the age-old requirements of safety and compliance remain very much unfettered by change. The innovation driven by new technologies is often constrained by these non-negotiable requirements, particularly in the nuclear industry.

The Shanghai Nuclear Engineering Research and Design Institute (SNERDI) is leading the way in implementing the next step in digitalization by bridging the gap between computer aided drafting (CAD) and computer aided engineering (CAE). The use of modeling and simulation in early engineering phase is constantly on the rise. One such step is accomplished by embedding Simcenter™ Flomaster™, the leading solution for thermo-fluid analyses within their Plant-CAD environment. The Plant-CAD environment typically includes 3D plant layout, process flow diagrams or process and instrumentation diagrams.

Integration of analyses in the design phase reduces precious engineering hours that are spent on model creation. Since the effort has already been spent once when drafting piping systems in the PlantCAD environment, this essentially highlights the severity of resource under-utilization in current workflows. This underlines an industry-wide need for a continuous and connected digital thread that streamlines workflows and forms the basis for innovation in the nuclear and plant and process industry.

Simcenter Flomaster is used for the design and analysis of multiple process systems of nuclear plants. The design workflow includes selecting the right equipment and analyzing multiple pipe and equipment arrangements to optimize design for safety and efficiency simultaneously.

The traditional modeling approach (figure 1) requires inputs from system flowcharts & pipeline isometrics to create the network schematic. This is done by assembling various components in the desired order and adding the relevant geometric and performance data to each of these components. This approach is typical of most CAE tools which are designed to operate independent of CAD.

Figure 3: 3D Model for CAP1400

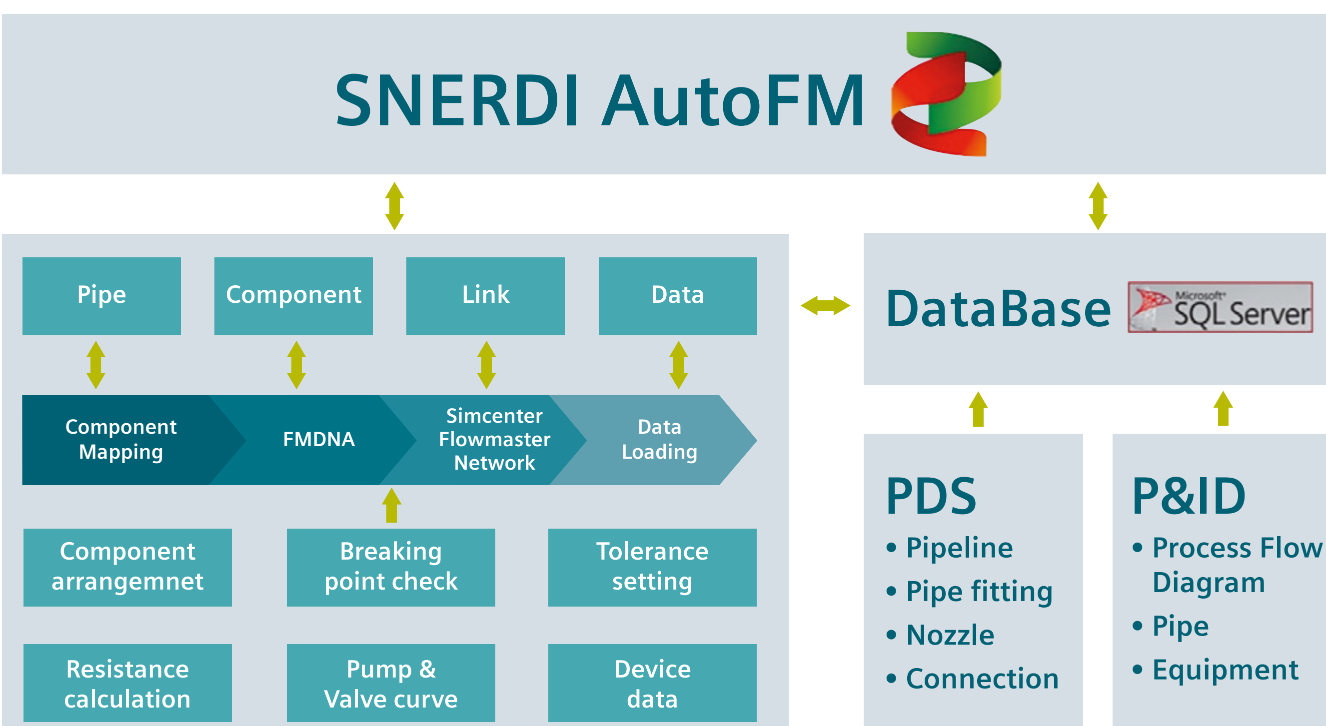


Figure 4: Workflow of AutoFM

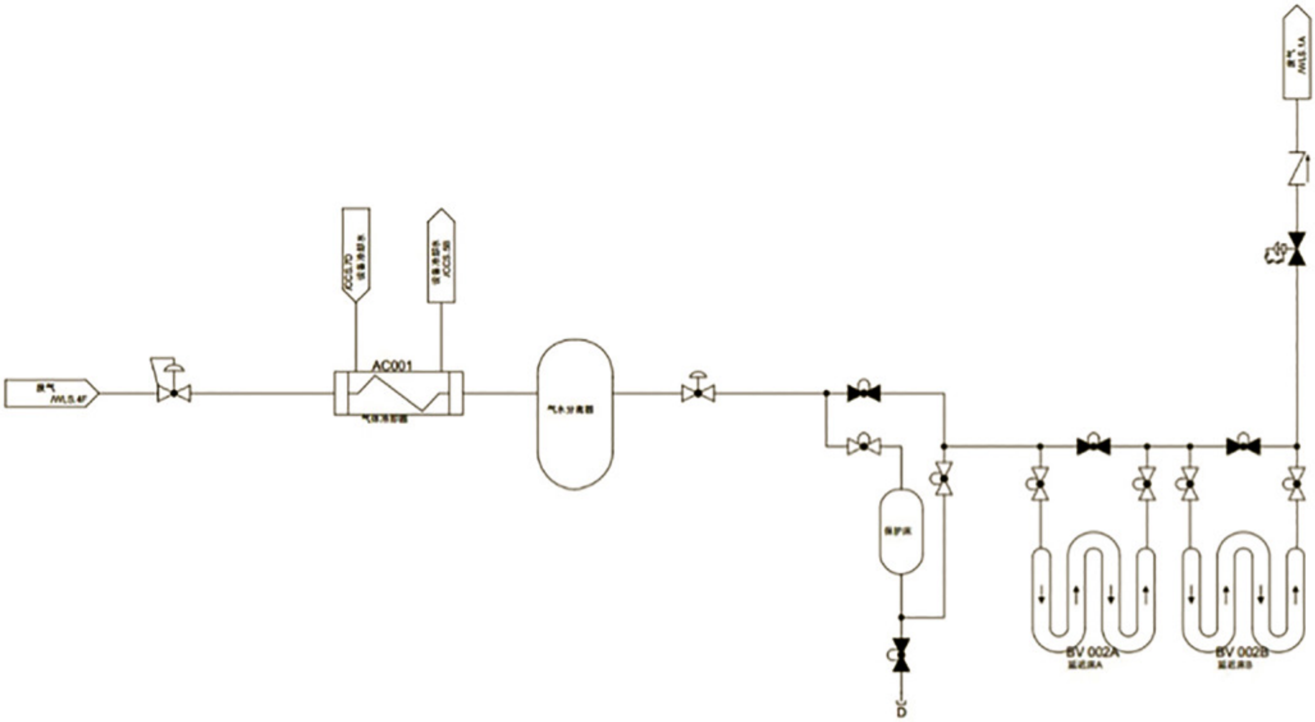
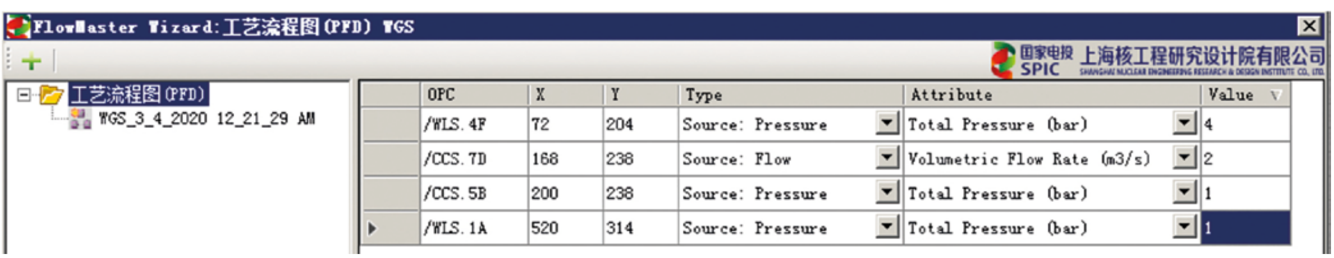


Figure 5: Example process diagram to be used for automated model creation



OPC	X	Y	Type	Attribute	Value
/WLS.4F	72	204	Source: Pressure	Total Pressure (bar)	4
/CCS.7D	168	238	Source: Flow	Volumetric Flow Rate (m3/s)	2
/CCS.5B	200	238	Source: Pressure	Total Pressure (bar)	1
/WLS.1A	520	314	Source: Pressure	Total Pressure (bar)	1

Figure 6: Plug-in launched from within CAD environment

> *"In case of larger systems the effort is reduced from a few months to a matter of few minutes. The larger the system and the number of components, the higher the ROI."*

Lin Chao,
Department of Process Systems,
SNERDI

Design is not simply geometrical drawing or routing layout modeling, but also understanding the implications of such choices on performance and safety to create viable and useful products. The purpose of CAE is to optimize and improve design based on its performance and function.

Moving beyond the traditional workflows to a more integrated approach leveraging digital data and models is an industry wide trend. A seamless integration of analysis into the design process is key to realizing the full potential of CAE. Simcenter Flomaster supports full product line development via its APIs which was used by SNERDI engineers to integrate CAE into a seamless single interface within their PlantCAD environment (Figure 2).

3D System Model

A process system model that includes P&ID and 3D piping model of CAP1400

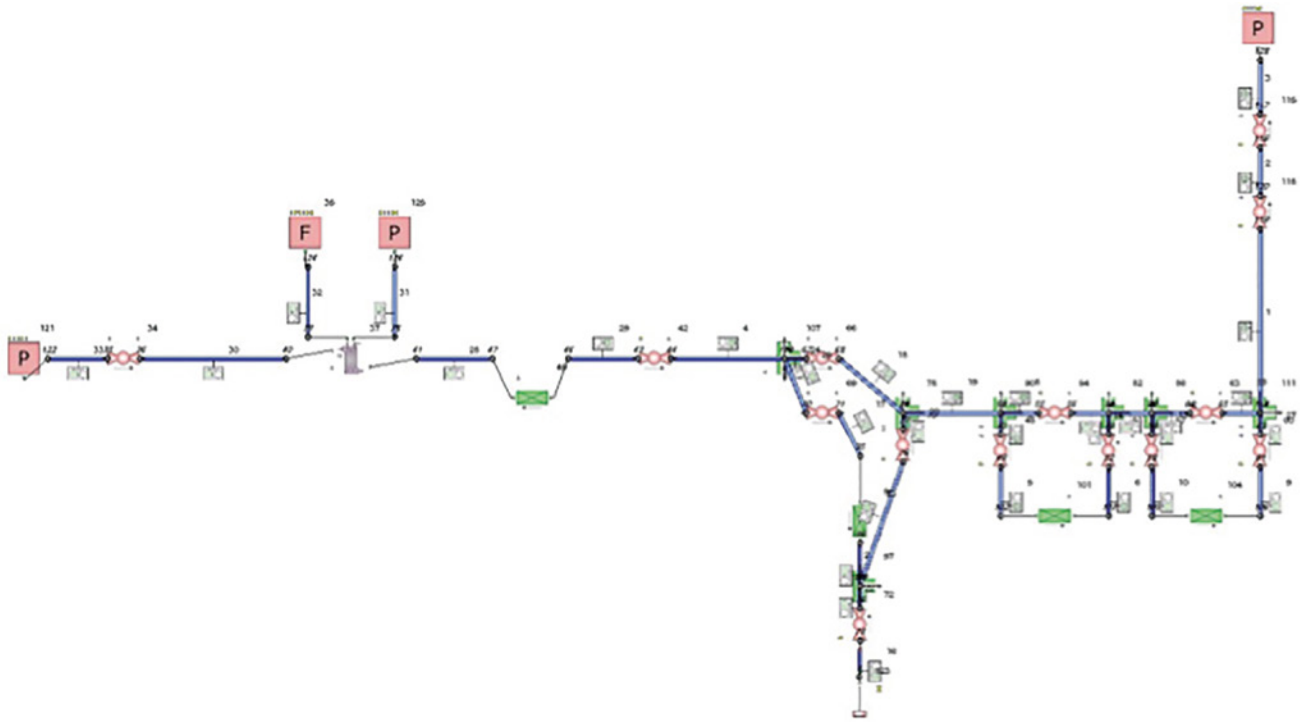


Figure 7: Automatically created and parametrized model

was established (figure 3) using dedicated P&ID system design software Intergraph Smartplant P&ID and 3D factory modeling software Intergraph Smartplant PDS/3D. The model library information was complete with interface development capabilities.

Workflow
Data for simulation are managed centrally where a client connects to a central server and relevant simulation data is stored in the same place. The schematic in figure 4 explains in detail how the central data server hosts not only the SQL databases needed by Simcenter Flomaster for simulation but also acts as a general repository for relevant data.

The mapping schema and sequence of component connections derived from the P&ID systems (Figure 5) is used to create an xml file as is required by the Simcenter Flomaster's command line interface in the form of an FMDNA (Flomaster dynamic network assembly) file. Using the open page connector tags, it is possible to collate multiple pages of process flows and identify appropriate process streams. The plug-in is then called from within the CAD environment (figure 6) and automatically picks up multiple process streams and system boundaries. A simplified drop down allows one to define the boundary either as pressure or flow and set appropriate values. Thus, the fluid system model creation is fully automated with placeholders for component specific data like pipe lengths, diameter and direct transfer of geometric information like T junction angles, nozzle dimensions etc. This minimizes any manual intervention and the automated setup is ready with all data validated by tight tolerance settings to provide valuable information on the systems' performance characteristics (figure 7). Data can then be exchanged in both directions creating a strong digital thread that combines Simcenter Flomaster as well as the Plant-CAD tool.

Benefits of integrated design
As a result of the implementation of this interface, all components and their dimensions are synchronized with the 3D models. The developed interface supports multi-dimensional modeling, such as interdisciplinary systems modeling and process and pipeline modeling. To implement this, a complete model mapping database was developed with methods to process break-points with tolerance checks for connectivity, component detection and model verification. A database for process equipment such as pumps and valves was also integrated as a part of the developed functionality. This allowed Simcenter Flomaster to be directly called from within the design interface.

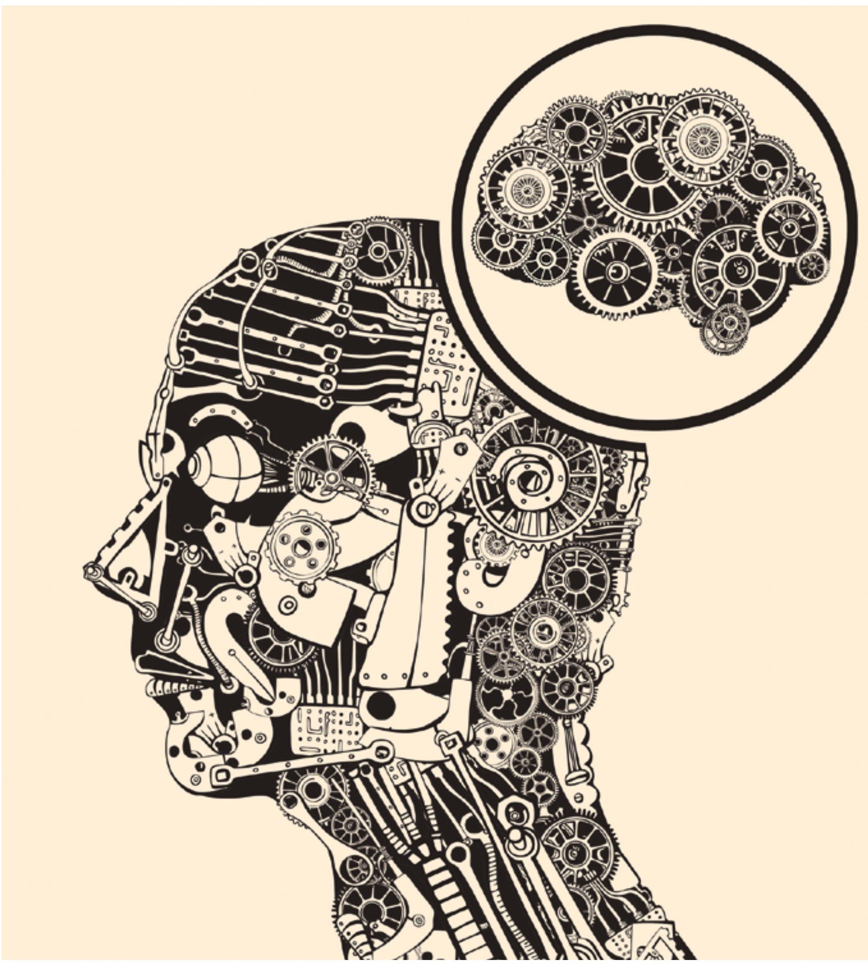
In conceptual design stage, design model changes frequently cause by process changes. This tool can quickly create a simulation model, provide a reference for the design based on Flomaster calculation results, and evaluate the solution more accurately. That reduce engineering changes by about 50 percent.

At the detailed design stage, the project focuses on verifying the resistance of the piping system, then calculates the pressure changes in both of pipelines, tees, elbows and other pipe fittings. The network modeling workload is otherwise huge and prone to errors. Combining P&ID and 3D models, automatic creation fluid network models improves modeling efficiency. For nuclear power plant systems, manual modeling requires 90 man-days, can be completed in nine man-days with this tool, a 90 percent increase in efficiency. ■

The Anatomy of a Digital Twin

A checklist to sort the digital twins from the digital sins

By Stephen Ferguson, Siemens Digital Industries Software



Everyone is talking about digital twins. And what is more, in the CAE world, everyone suddenly seems to have a hard drive full of them. But is every simulation model a digital twin? In this article, we'll explore what digital twins are, and come up with a simple list of criteria that will allow you to tell if your simulation model is a digital twin (or a digital sin).

Beyond the hype
Digital twins are quite literally in a state of "maximum hype," according to the Gartner Hype Cycle, which plots new technologies from emergence through to adoption in the market.

In the 2018 Gartner Hype Cycle, digital twins occupied the very top of the "peak of inflated expectations" (which is the state of maximum hype). The Hype Cycle predicts that, after this point, new technologies inevitably plunge into the "trough of disillusionment" (where interest wanes as early adopters fail to realize the promised potential), before hopefully emerging onto the "plateau of productivity" (mainstream adoption).

Since digital twins did not appear on the 2019 Hype Cycle, we can only presume that they are already descending rapidly into the trough. While I am confident that they will eventually emerge into productivity, while we are waiting, we should probably get a few things straight. Like what actually is a digital twin?

If we are truly going to move beyond the hype and into productivity, we need to be honest with ourselves, and each other, about what a digital twin is. But how to define one?

The answer, I think, is anatomy. In the same way that an anthropologist might describe the difference between a human and a chimpanzee (both apes), or a zoologist might represent the difference between a monkey and a squirrel (both mammals), we need to define an essential set of characteristics that every digital twin must exhibit to justify being called one.

But before we get into the details, it's worth spending a little time to familiarize ourselves with the basic concept, which is incredibly simple:

"A digital twin comprises a Real Space (a physical asset), a Virtual Space (a digital model), and data flow between them, such that the digital model can be updated to reflect the state of the physical asset."

The Six Characteristics of a Digital Twin

1. **Real Space:** a digital twin must be accompanied by a physical asset

   This first characteristic should be obvious. As with biological twins, a digital twin must comprise two siblings, one of which must be a real-life physical asset. If you can't touch its counterpart, then it probably isn't a digital twin.

   This most obvious criterion is the one by which (from a simulation engineer's point of view) most of our "so-called digital twins" stop being twins. As simulation engineers, we pride ourselves on the veracity of our models. We go to great lengths to capture all of the relevant physics to make our models accurate facsimiles of real-life products, but this alone is not enough.

   As discussed in the next section, this should is a challenge rather than an obstacle.

   In some cases, such as aircraft, spacecraft, racecar, or yacht development, the results of multiple simulations are used to build a simulator that replicates the behavior of the (as yet unbuilt) real-life asset. These simulators are often used to train crew and to refine performance. Even though simulators are not the final physical asset, they are physical in nature, and their use informs and evolves the underlying virtual model. In my opinion, they satisfy this first criterion.

2. **Virtual Space:** a digital twin must include a high-fidelity digital model of the asset

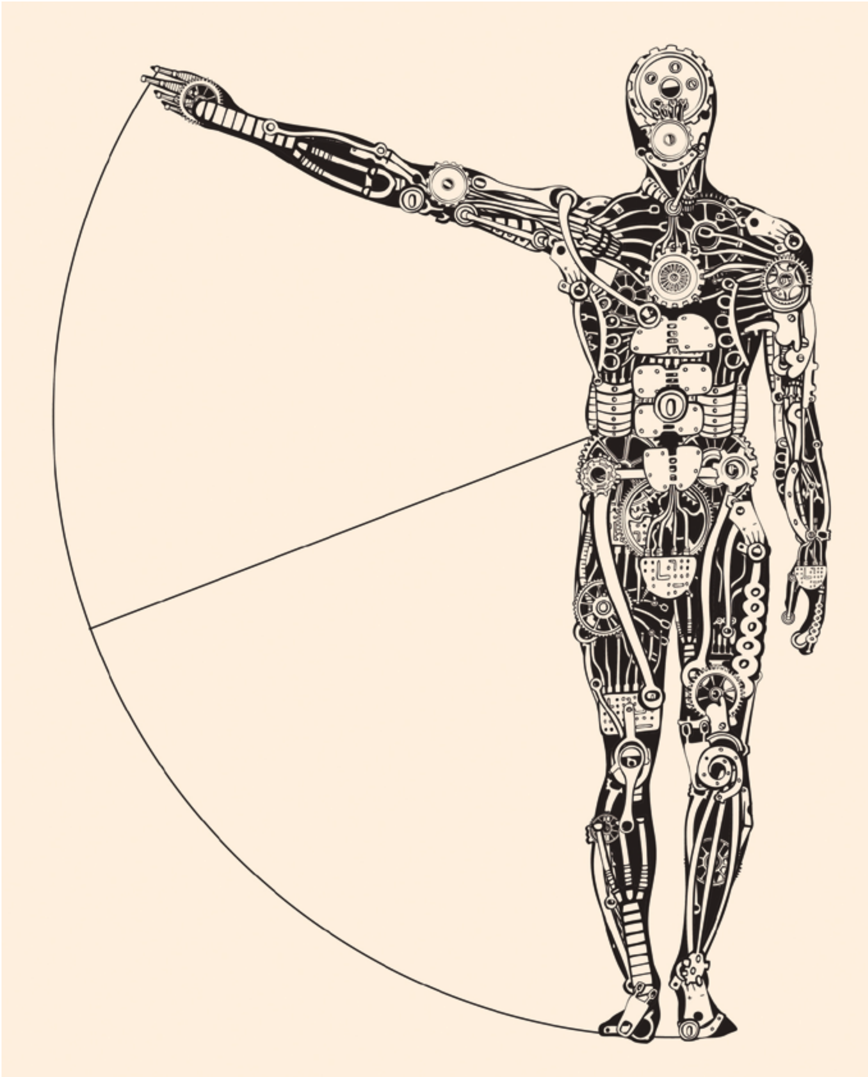
   As simulation engineers, we spend much of our working lives building, perfecting, and inhabiting virtual spaces. They are our natural habitat. Most experts would agree that our models are an essential part of the digital twin.

   By definition, biological twins are conceived together, born moments apart, and often live parallel lives. This is not, and cannot be, the case with digital twins. Significant physical assets are always born from a digital prototype, which, by necessity, will exist long before the real-life asset is manufactured or enters production.

   At the very least, this will include the three-dimensional CAD model that defines the physical shape and properties of the product and guides its manufacture. Usually, it will consist of multiple simulation models predicting the asset's performance in the real world. These simulations not only guide the evolution of the design, but they also adapt along with it.

   Unfortunately, all too often, these simulations are useful only through the product development process. Once the physical asset enters the manufacturing and operational phases, these simulation models are often either archived onto a tape or stored in a dark and dusty corner of the PLM database.

   This is a wasted opportunity considering the intellectual and computational effort that goes into creating these complicated solutions. In the CAE world, we have often talked about "product life cycle management," in many ways digital twins realize that ambition. Rather than packing away our simulation models at the end of the project's design phase (archived onto tape drives or put into remote storage), the digital twin grants them an extended life.



3. **Connected:** there must be data flow between the virtual and real spaces.

   The Real Space and Virtual Space need to be connected by a stream of data that (at the very least) updates the virtual twin about the "as is" condition of the real-life asset.

   As simulation engineers, we are often forced through a lack of data to approximate boundary conditions and simplify operating scenarios. Digital twin technology will change that forever; as we accumulate data about a physical asset's real-world performance, we can use it to challenge our assumptions and refine our models.

   Truly accurate prediction depends on acknowledging those occasions on which our simulations fail to capture the real-world performance of a physical asset accurately. The digital twin gives us an unprecedented opportunity to verify, validate, and ultimately improve our simulations against real-world operational data rather than contrived experimental tests.

   This data will be useful for guaranteeing and improving the performance of existing physical assets. It will also inform future generations of the same product family.

4. **Adaptable:** the virtual space must respond to changes in the real space

   The whole point of the digital twin is that the virtual space is a mirror of the real space, evolving, aging, and adapting to the wear and tear of operation and reflecting any maintenance performed. A digital twin should be used to analyze and simulate real-world conditions, respond to changes in its environment, improve operations, and add value.

   Adaptability can extend to the physical asset as well. Executable digital twins or xDT for short embed simulation models into the physical asset. These models can run on edge devices or on the cloud and can even run in real-time in cases. One can think of it as a digital twin, used outside the traditional CAE environment and turned into an executable asset that makes processes, products, sensors or controllers smarter and hereby opening the road to new business cases. The executable digital twin in this case is allowing the physical twin to adapt better to its environment.

5. **Predictive:** the virtual space must predict the performance of the physical asset .

   As simulation engineers, the challenge is for us to make our simulation models versatile and robust enough to live alongside the physical asset for its entire operational life, providing a predictive engine to answer the "what-if?" questions that only arise in operation.

   By the most basic definition, the virtual space could just be a simple record of the condition of the physical asset, detailing its current state and that of the individual components from which it is built. Although this limited implementation might be useful in some regards, with no ability to predict the asset's future performance (either under standard operating conditions or under some extreme eventuality), then the utility of this "dumb" twin is severely limited. For a digital twin to realize its full value, it needs to be predictive rather than just descriptive.

   The reality is that - for now at least - if you need to answer "what if?" questions about the performance of your digital twin, then simulation is the only game in town. If I want to find out what happens if I drive a brand-new sports car through half a meter of water, I can either drown the physical asset or run many simulations on its virtual counterpart.

The list of potential questions is endless:

> "What happens to the emissions signature if I run my gas turbine on hydrogen rather than methane?"; "If I change the ride height of a vehicle to avoid underbody damage, how will that influence aerodynamic performance? ; "How can I adapt the control systems of my subsea compressor to cope with unexpected pressure differences in the reservoir?".

CAE simulation has a long history of providing the answers to difficult engineering questions. This capability will only be enhanced when fed with real-life data from the physical asset. I think it's fair to say that, without a credible predictive capability, then a digital twin isn't really "alive." Engineering simulation is the beating heart of the digital twin.

6. **Threaded:** the virtual space will comprise multiple interacting models that together predict performance

For a digital twin to act as a fully comprehensive facsimile of its real-world counterpart, it must be able to predict and analyze a wide range of physical phenomena. This sort of cross-domain predictive capability will necessarily involve many different engineering and simulation tools, working together to provide answers.

The state of the art in engineering simulation is evolving all of the time. The distinctions between different CAE disciplines are becoming increasingly blurred. Fluid simulations often include structural mechanics, structures simulations often include fluid dynamics, and systems simulation by definition include a wide variety of physical phenomena. However, it is doubtful that a single "grand-unified" CAE model will ever provide all of the predictive capability required to fully realize the potential of the digital twin. The virtual space will necessarily comprise of many models, working in isolation or together.

The point of this is that we don't have to work too hard to make our models comprehensive, especially if the cost of that is a reduction in robustness. Part of the skill of a CAE engineer is working out which physics to include in a simulation, and which can be safely ignored (or modeled using a different method). We should never be scared of simple models that reliably predict real-world performance. At least in the early days of the digital twin era, robust, simple, connected models will be more useful than "grand-unified" simulations.

Conclusion

The simple conclusion to this exercise in anatomy is that, while no single CAE model can be a digital twin in its own right, any credible digital twin must be powered by CAE simulation's predictive capabilities. As the digital twin emerges from hype into productivity, it provides an opportunity for engineering simulation to become more useful, more accurate, and more widely adopted than ever. But please stop calling every simulation model you create "a digital twin." ■

Unlock innovation and lifecycle optimization

Where do your ideas for innovation come from? After all, inspiration can strike from the unlikeliest of places.

Some are blessed with unending imagination.

Some take inspiration from nature.

Some are hit by ideas when walking, driving and even sleeping. But sometimes inspiration needs a helping hand. And that's where we come in.

Usually when designing a product, you start with requirements. You rapidly move to developing concepts and designs for components or systems. Simulation and test are then used to check whether the proposed design meets those requirements. And this is exactly where Simcenter can bring a paradigm shift. Generative engineering can help you explore your design fully. Together with AI you can automate and streamline the process of generating, evaluating and refining designs that meet those requirements. Thus helping you accelerate the pace and scope of innovation.

There is also an increasing opportunity for you to use the models built when designing the product towards downstream activities to optimize their full lifecycle, so called continuous engineering. You can even take it one step further. Embed digital twins within final products to enhance the performance of those products.

This is not pie in the sky technology. Read how Simcenter customers are using simulation and test to push the digital twins of their products farther, faster and more efficiently. In this section of Engineer Innovation, we bring you some of those stories alongside technical articles.

Designed by the flow

HP and Siemens redefine the impossible with additive manufacturing and computational fluid dynamics based topology optimization

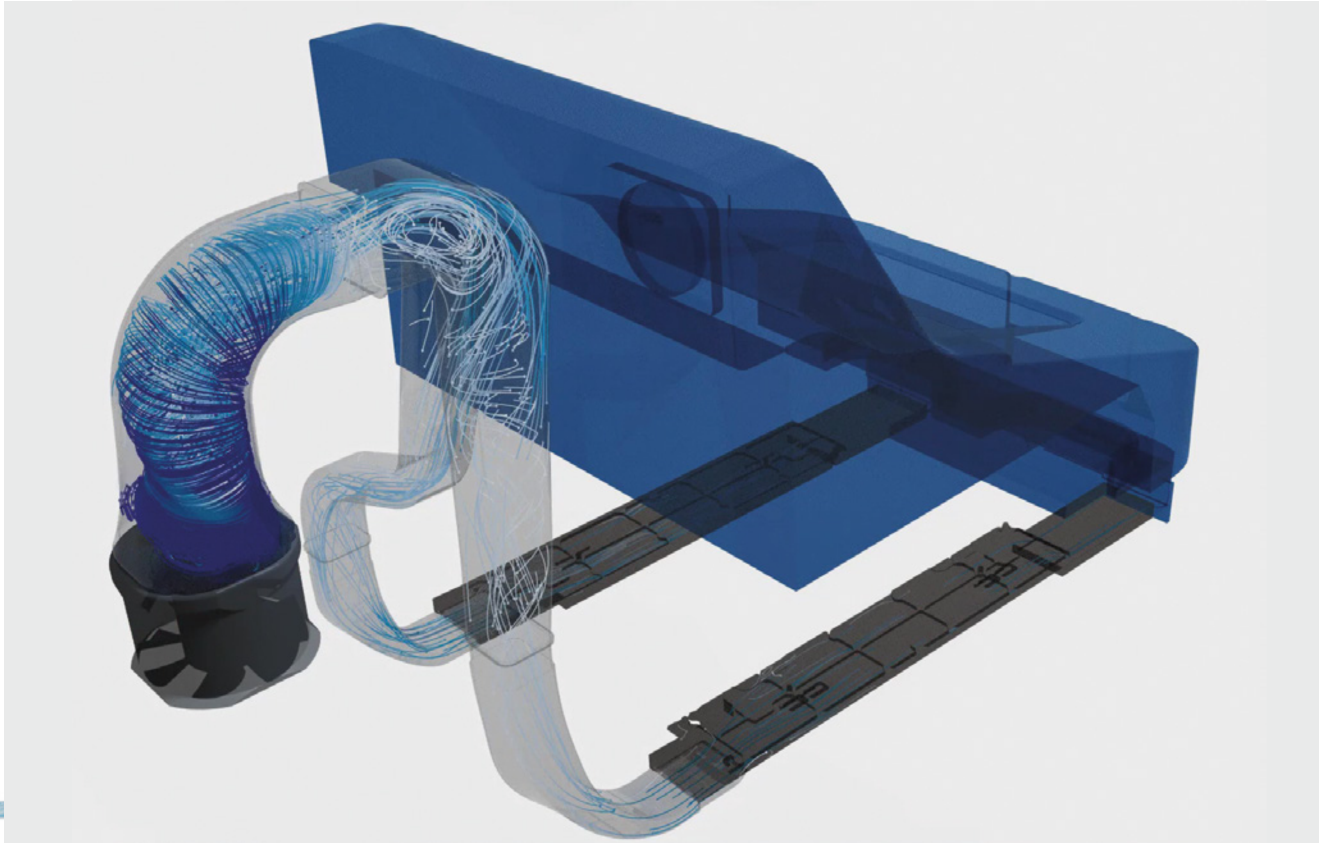
By Simon Fischer and Julian Gänz

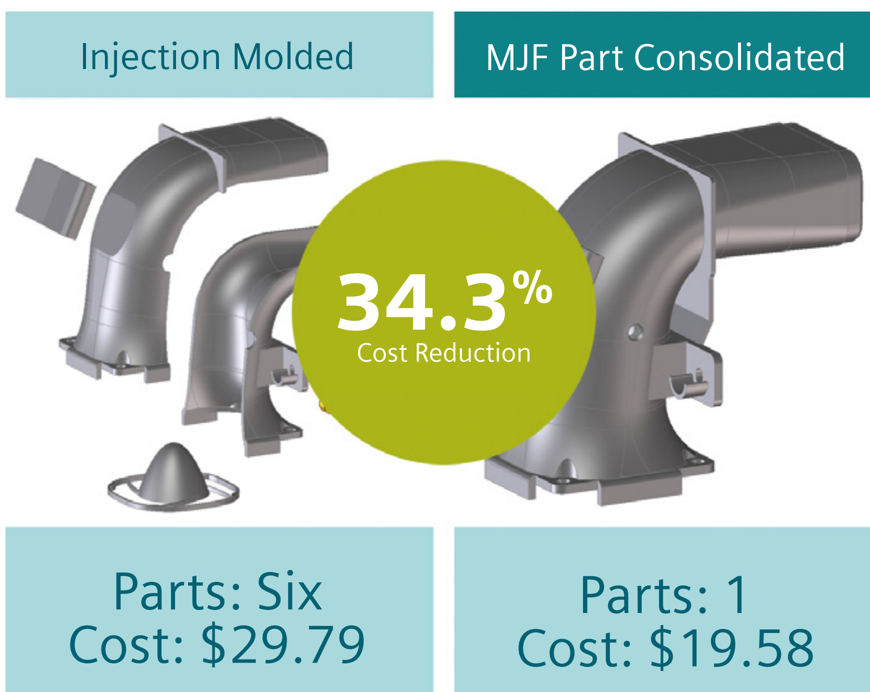
In 2016 McKinsey & Company published a study on additive manufacturing readiness for industrialization. One of their major findings was that "capturing the technology's full potential often requires completely rethinking the way products are designed." [1] One of their staggering conclusions was "that companies are only scratching the surface of what is possible." And while the report is now more than three years old and the technology has clearly made significant steps forward, the question remains, "how far companies have really pushed in the meantime to truly embrace the potential of additive manufacturing?"

HP– A printer prints its own parts

One player that is heavily involved in driving the industrialization of additive manufacturing is Hewlett Packard. Now, everyone knows that HP manufactures printers. And among those are 3D printers. If you investigate the details of 3D printing technology a key to efficiency is the cooling of the printer heads. The more moderate the temperature of those heads, the faster you can print and, as a bonus, you will need to replace them less frequently. In HP's 5200 Multi Jet Fusion printer the cooling of the two printer heads for black and color is done through air guided by a cooling duct which transports cool air from the so called 'lung' of the printer (outside the build chamber) into the build chamber itself. The key component for the cooling efficiency of the duct is the intake bend closest to the fan that drives the air flow.

In a first step of embracing their own additive manufacturing technology HP had already used 3D printing to



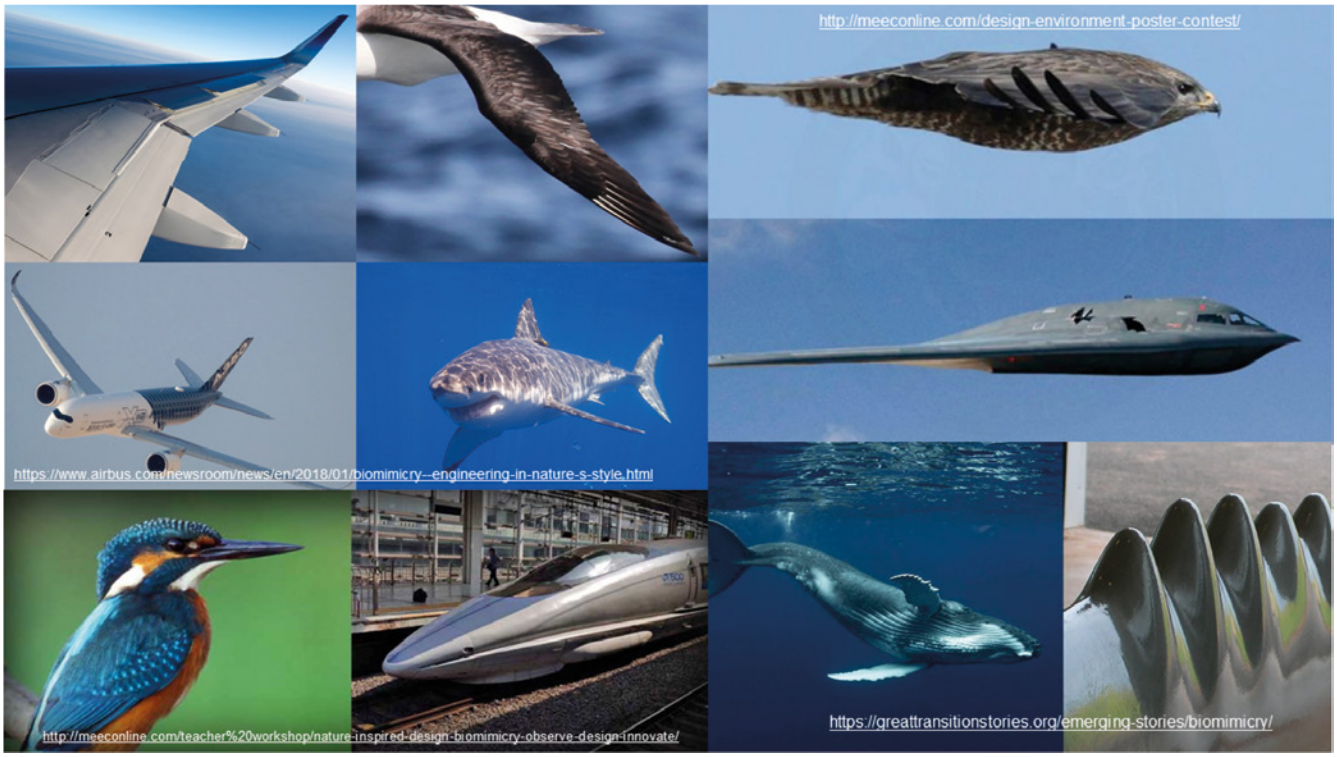


consolidate parts on the intake of the duct, thereby significantly reducing its costs. By transferring the traditional production process from six individual injection molded parts into one single multi-jet fusion printed part thus eliminating the need for assembly and leakage testing, HP was able to reduce the production cost per part by 34 percent. This was the first HP printer that managed to print one of its own parts.

But coming back to the statement from McKinsey about just scratching at the surface this is not where HP engineers stopped. Their goal was not only to reduce the production cost but at the same time increase the cooling performance. Let's take a small detour first...

Panta rhei

- everything flows, is not just an ancient philosophic buzzword: If you carefully look around you, you will realize there are fluids and flow all around us and there are amazing solutions from nature to tackle the associated flow problems. For sharks, evolution came up with an amazingly streamlined nose shape to move fast through the water. Eagles have evolved winglets to optimize flight efficiency. Over decades rivers found the best possible ways through a given environment thereby shaping terrain



for a better throughput. Wind has morphed trees to minimize the drag on them; and sand driven by the wind creates an aerodynamically efficient bulk of grains, also known as dunes. Our very own heart is a flow optimized solution to transport blood through our body in the most economical way. etc.

The problem with biomimicry
In recent decades engineers have started to leverage the power of those solutions in nature and began to mimic them to solve related fluid dynamics engineering problems. This discipline has become very famous as Biomimicry or Bionics. And while this is undoubtably amazing engineering, there are several limitations associated with this approach. Firstly, as all those solutions result from an evolutionary process, it implies it takes thousands if not millions of years for nature to having come up with them.

Secondly, does not always come up with a flow optimized solution that is relevant to the engineering problem at hand. For sure, the shark nose has inspired several automobile manufacturers in their aerodynamic solutions, as have eagle wings for the aerospace industry, but for most of the flow challenges the question with biomimicry remains: What if nature has not (yet) delivered the blueprint to solve your engineering problem? And you cannot wait a few thousand years hoping for the solution to accidently evolve. And the likeliness is high that nature has not yet made relevant design-proposals for an efficient cooling duct for 3D printers.

Thirdly, many evolutionary designed flow solutions involve organic shapes that do not fit into the limitations and mindset of traditional computer aided design and manufacturing technology. All too often even the most efficient solution is dropped as it simply can’t be manufactured.

But let’s imagine what would happen, if we dont limit ourselves on mimicking the few flow-optimized designs that evolution came up with, but instead we mimic the evolutionary process itself, but evolution a million times faster. And then we add on top a way to manufacture even the most unusual uncompromised designs. While this may sound like science fiction, in truth today’s engineers hold all relevant tools in their hands to make this vision a reality.

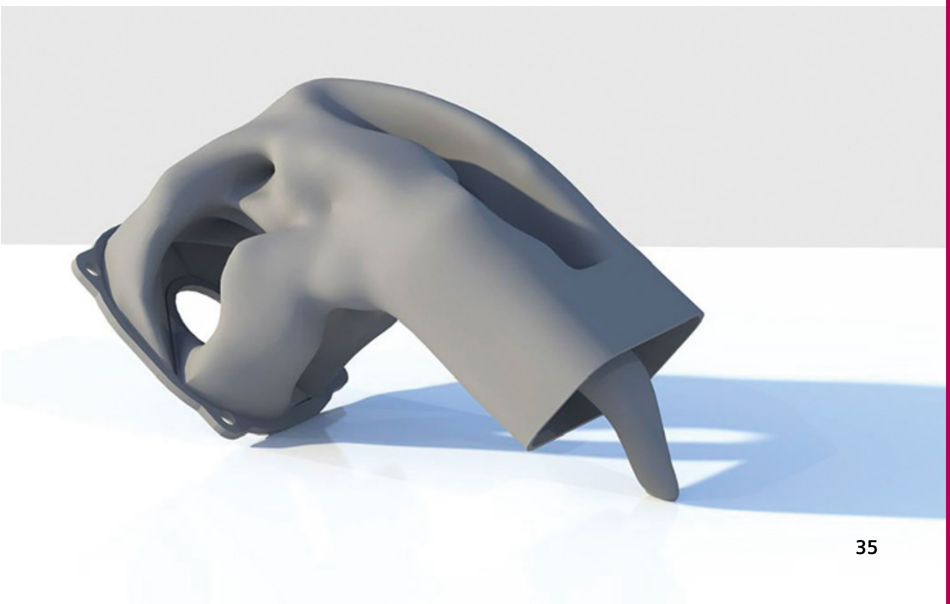
And this is exactly what the engineers at HP and Siemens saw.

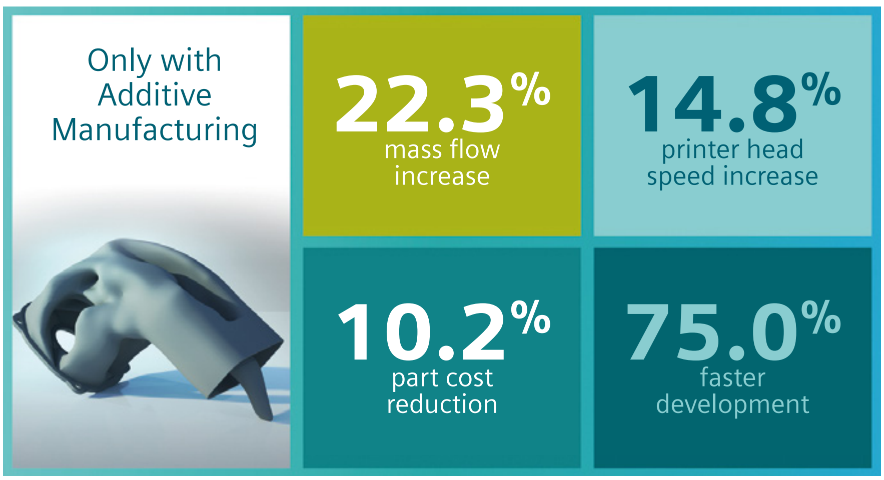
The evolution of the mighty duct
Three things are required in order to redefine the impossible: first computational fluid dynamics; second topology optimization; and third, additive manufacturing.

So, the first step to improve the cooling performance of the duct, was to understand the status quo through CFD simulation. As the study immediately revealed the baseline design is characterized by a strong swirling flow. The latter is caused by the fan that is rotating at a few thousand rpm thereby driving the air through the cooling system. Obviously, the tangential swirling motion is of no benefit to the desired directed air flow through the duct. The secondary motion causes losses through undesired turbulence generation that is of no benefit to the effective mass flow. And while many traditional engineers would potentially have come up with a static flow straightener or honeycomb pattern, the engineers at HP and Siemens took a completely new route.

Rather than following the beaten track, the engineers embraced topology optimization embedded in the CFD tool. In a first step the design envelope was opened to the maximum available space that avoided interference with other parts of the carriage assembly. In a fully automatic iterative process the CFD simulation is used to assess the flow through the air duct, starting from the maximum available fluid volume space. After the CFD has reached a converged steady state solution for the given fluid domain, the adjoint function was assessed. This is a quantitative measure for the effect of any local fluid volume, i.e. computational cell, to the global cost function, in this case the backpressure or the massflow rate through the air duct. In addition an equal mass flow split between the two printer head channels is envisaged through the cost function to ensure equal cooling performance of both the color and the black head. The algorithm then automatically starts to convert those local areas that have a negative impact on the overall massflow rate and balance by converting them into impermeable walls. After this step the CFD solver reassesses the flow for the modified fluid domain and the loop starts over.

By these means the topology of the fluid airflow path evolves; improving the massflow rate with every iteration





and reaches a saturated high performing state after around 80 iterations, taking less than 8 hours on 100 CPUs.

It is the flow itself that has become the new designer, just like a river defining its way. But in hours, not ages.

The result is a shape with a rather organic appeal that would never have been considered by any traditional engineering design procedure. So, the question to HP engineers was, can this unconventional design truly improve the performance? As the CFD based comparison between the baseline duct and the newly topology optimized duct indicated, the undesired swirl in the wake of the fan was indeed massively reduced and the adjoint method found a way to direct the flow around the bend thereby minimizing secondary flow structures and streamlining the flow within the shortest possible distance.

And all that without any flow-straightening auxiliaries causing additional back-pressure. This all sums up to a digitally predicted improvement in massflow rate of more than 22 percent. A number that according to HP engineers translates into 15 percent faster printing speed. And while the original duct development time was about 4 months, the new designs was achieved in four weeks of total development time, which is 75 percent of the one required for the baseline assembly.

Unleashing the potential through Additive Manufacturing

In the old manufacturing world, the story would have stopped here -it probably would have never been told. The design from the optimization process would have been labelled as another interesting but irrelevant exercise by some CAE engineers. Why? Because no one would have been willing or even able to bring this part to life with traditional manufacturing methods at a reasonable cost level. But not this time. Needless to say HP had all the hardware in place to just print the new part, supported by Siemens software to preprocess the topology-optimized duct and nest it for the print job. And so, the new duct became reality just like the original non-optimized 3D printed design but with an expected performance increase of more than 20 percent.

Will the Digital Twin keep the promise?

But then of course, that digital twin is still of no value if it does not represent reality. Skepticism was indeed high, especially among experienced flow engineers, when they first held the unconventional part in their hands. So, after realization of the new duct, HP engineers took the part to the flow test bench. And the message was clear when they were measuring an increase in massflow rate of 20-23 percent exactly like the digital twin predicted. This finding concluded the evolution of a simple black plastic part into what became famous as “the mighty duct”.

Putting computer aided engineering processes upside-down

And while the story at hand takes place inside a printer head carriage assembly it could as well be taking place in a car, an airplane, a chemical engineering plant, a smart phone or any other product or device whose performance is heavily depending on the physics of fluid dynamics. With this project the engineers at HP and Siemens have put the CAD/CAE/CAM world upside down and delivered a blue-print to the future of engineering across all industries. Together HP and Siemens realized a piece that has been designed by the flow. Without being able to be specific back in the days, this is probably what McKinsey meant when they stated, "capturing the technology's full potential often requires completely rethinking the way products are designed." This scratch is a deep one.

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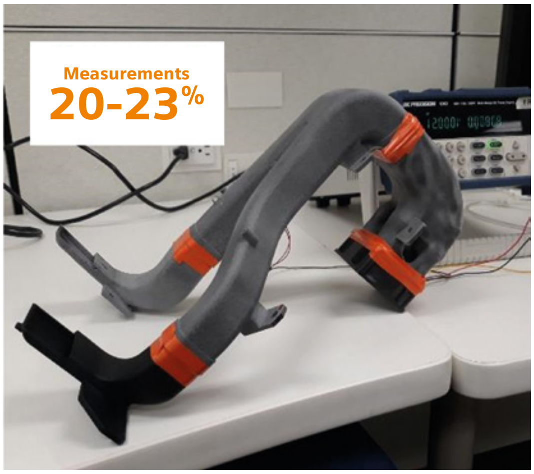
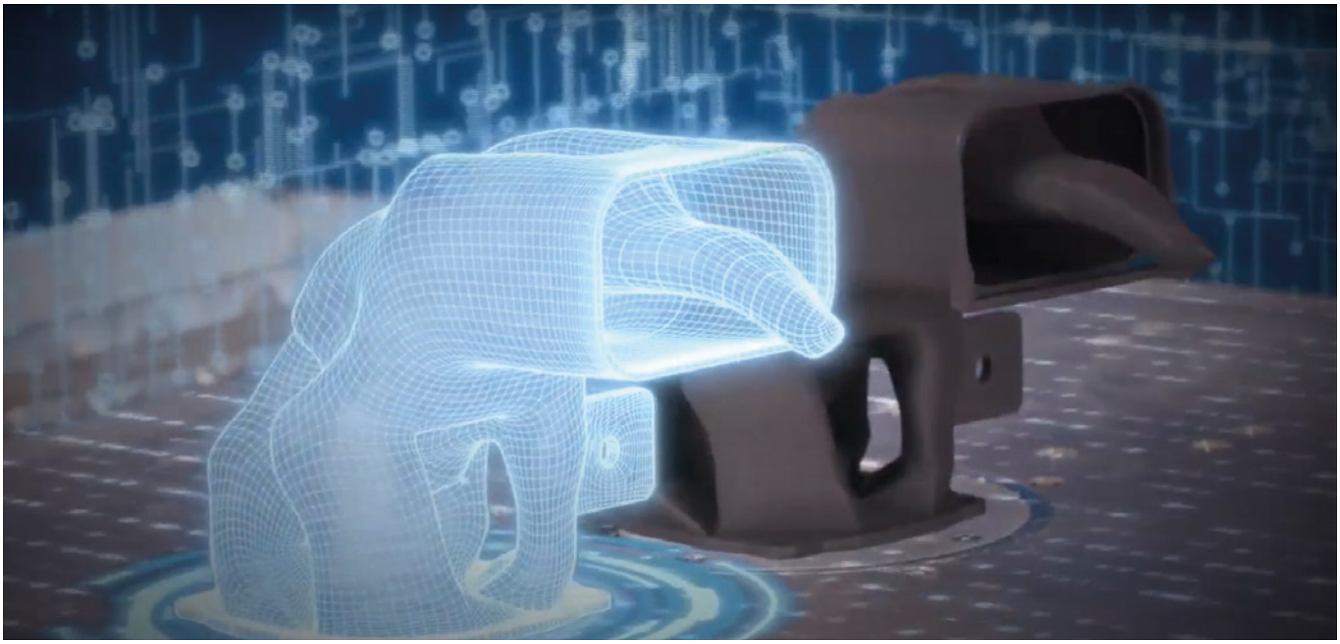




AZL realize early system optimization

German acoustic expert uses Siemens' solutions to enhance electrical and autonomous vehicle development

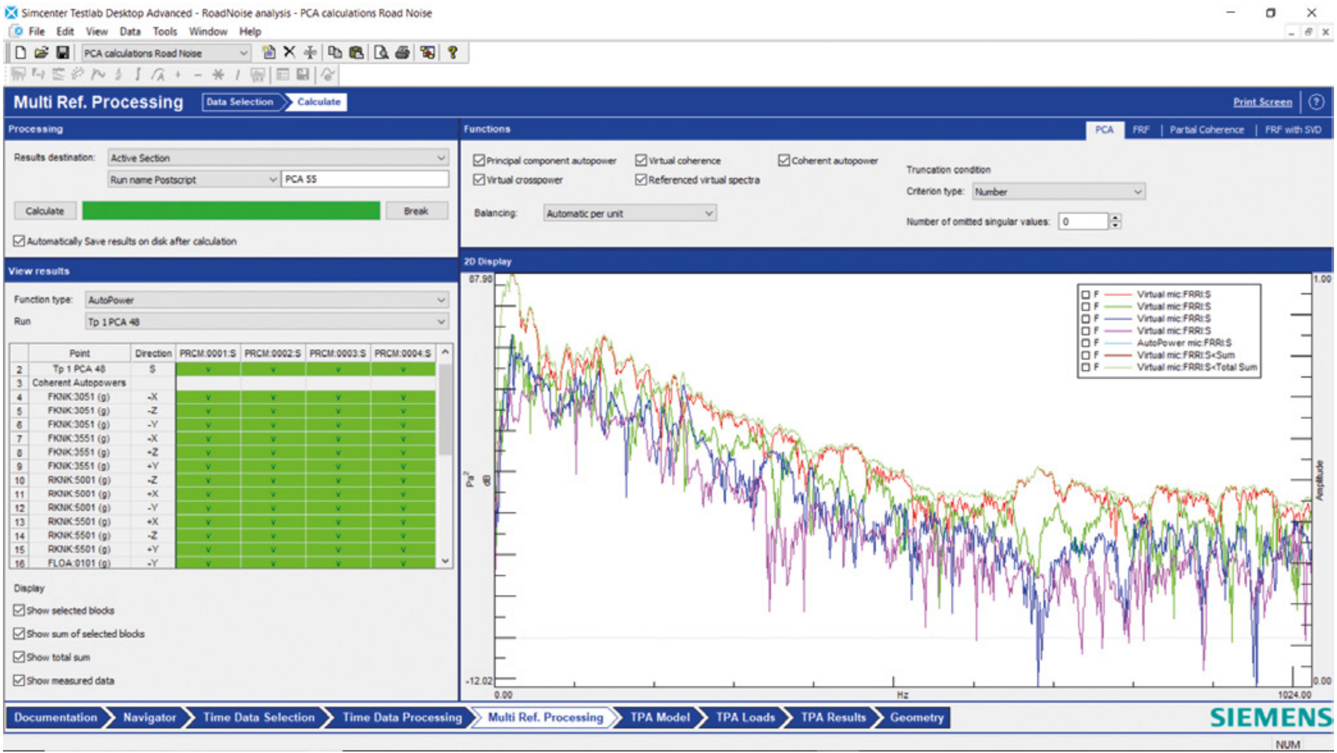
Addressing emerging NVH challenges
AZL, a German acoustic test bench manufacturer and engineering consultant serving the automotive industry since 1999, recognizes the ongoing challenges related to electrical vehicle (EV) and autonomous vehicle (AV) development. To tackle the new noise, vibration, and harshness (NVH) development needs, AZL is implementing innovative technologies such as component-based transfer path analysis (TPA) and model-based system testing (MBST).

With these technologies in place, AZL builds special test benches addressing emerging NVH challenges to provide their customers with innovative testing procedures resulting in information outlining how to optimize the AV and EV NVH performance in much earlier development stages.

Emerging NVH challenges in AV and EV development
According to Andreas Schilp, managing director, AZL-Technology Center GmbH, the development of AV and EV brings three main challenges and opportunities into play:

First, high frequency structure born noise becomes more important with EV, meaning that bushings and mounts need to be developed with the proper stiffness characteristics in this frequency range. New test benches that can handle this need to be developed.

Second, as the combustion engine, a very important masking source at low speeds, has disappeared, the structure borne road noise is significantly more apparent. Due to that, the development of good suspension systems is a high



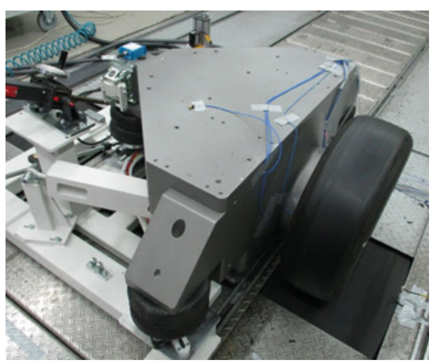
priority for customers. AZL is active in the development of the right test benches to better cope with road noise and strives to acquire the necessary data to validate simulation models. The company also develops tests not only on the full vehicle level but also for the isolated suspension system levels, such as testing only a front or rear suspension system separately on the chassis dyno.

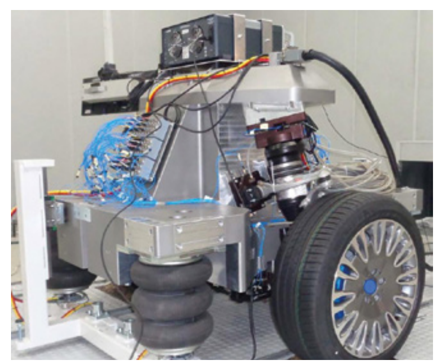
Finally, AZL is exploring options to transfer these component and system test results into the simulation world as part of the product's digital twin. To achieve an accurate digital twin, the simulation model needs to be fed with accurate data.

Next generation vehicles require new development processes

The concept of a digital twin goes hand-in-hand with the growing trend in the industry. Instead of testing the final full vehicle, physical testing takes place earlier on the system and component levels. This approach can significantly shorten the vehicle development cycle as it affects the AV's and EV's producers, who are pushed to re-think and innovate the development process.

"For EV development, we try to step back from full vehicle level development and

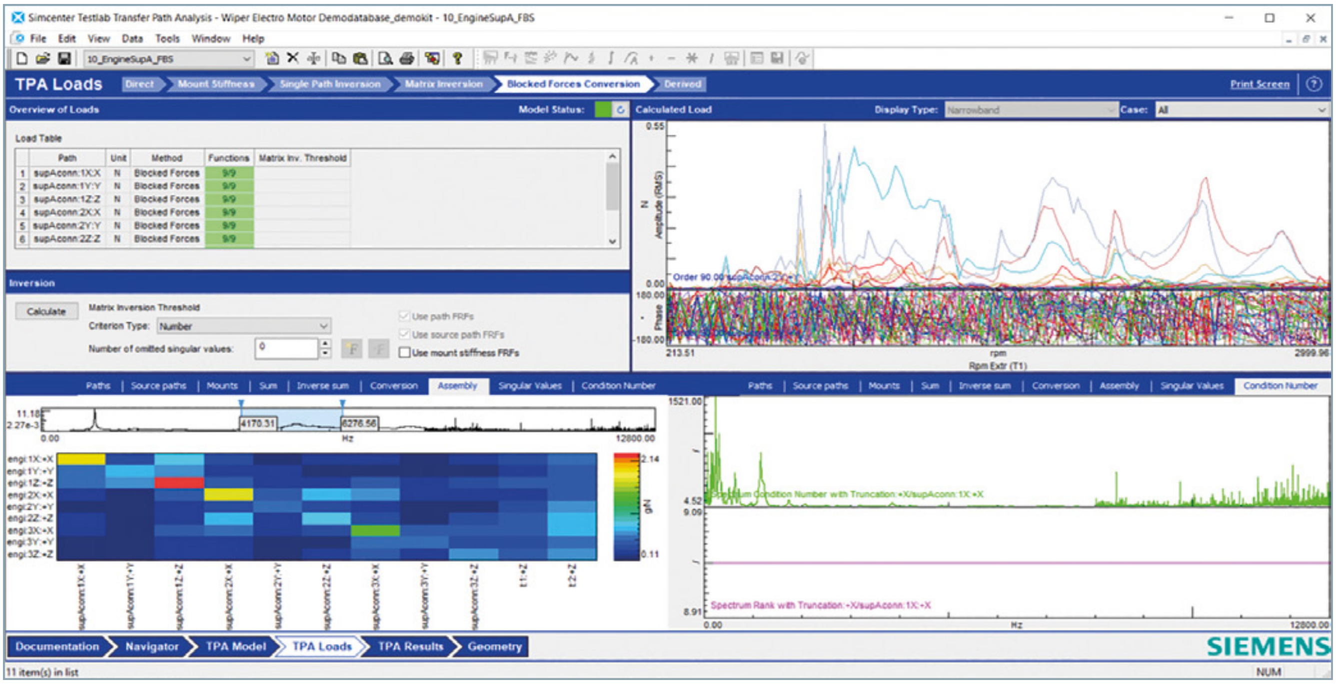




intensify our focus on the system and component levels; the same is true for optimized development cycles due to the new homologation processes," says Schilp.

In the best-case scenario, the development starts with setting up simulation models. AZL builds special test bench capable of testing NVH on the component and system levels with carefully described boundary conditions. "As a test-bench manufacturer we provide our customers with clear guidance," says Schilp.

To accurately acquire the test bench data, AZL relies on Siemens Digital Industries Software solutions Simcenter Testlab software in conjunction with Simcenter SCADAS hardware, which is



"The ability to calculate interface forces from the blocked forces is one of the building blocks that would enable virtual vehicle assembly."

Andreas Schilp
Managing Director
AZL

compatible with a wide range of sensors and data interfaces.

"What makes the Simcenter portfolio unique is that it imbeds a close integration of test results with simulation results to compare them directly in exactly the same environment," says Schilp.

Block forces in the NVH vehicle development

The rising trend towards system-based development sparks a new technique named component-based TPA. TPA consists of the assessment of blocked forces (and moments) as a characterization of the system.

"The importance of blocked forces in our development is that it allows you to split systems from each other," says Schilp. "We have to split them in terms of interacting forces and interacting moments. These interacting forces are not invariant and depend on the full assembly, while the blocked forces are characterizing the system itself."

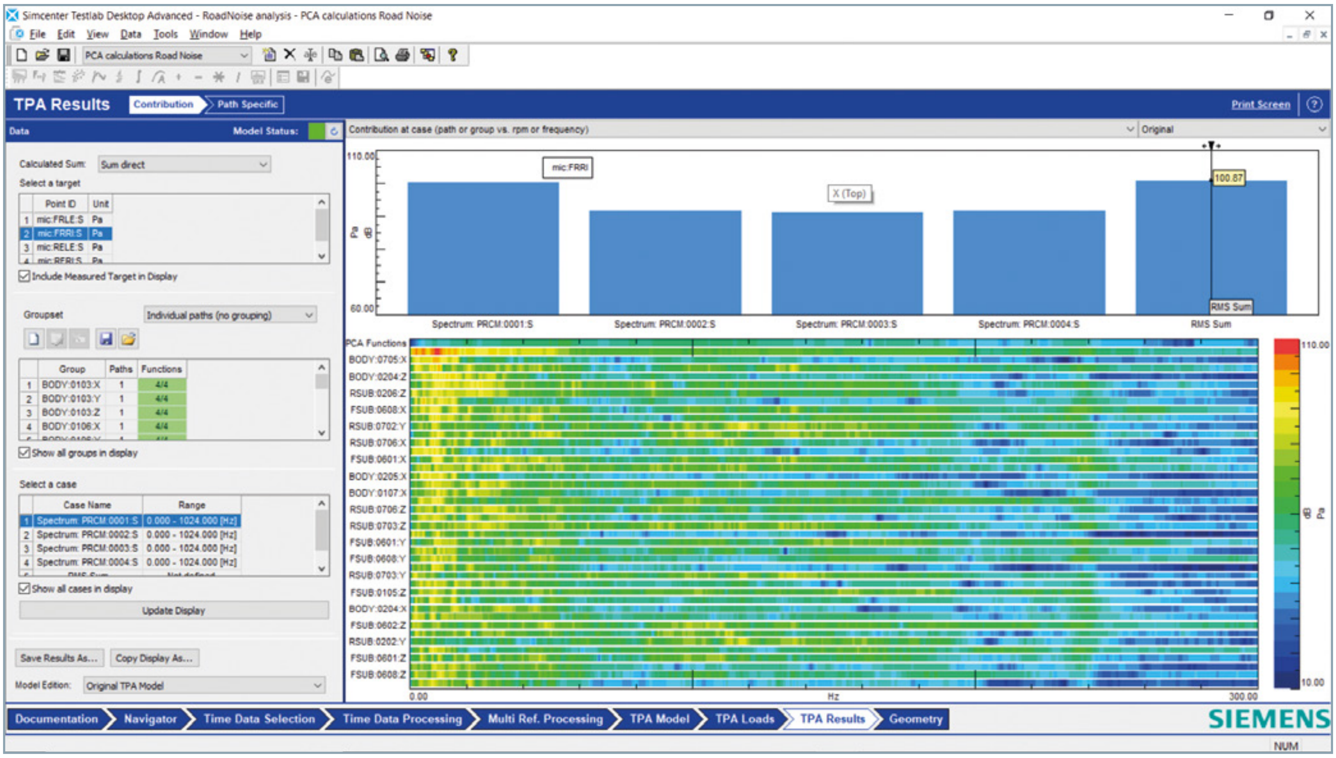
Having a characterization of the systems that is independent from the later integration opens great potential in the automotive original equipment manufacturer (OEM)-supplier trade relationship.

"With the 'blocked forces' approach, you don't have to first integrate the component in the full vehicle and then make your supplier responsible for something that is the outcome of the full vehicle," says Schilp. "But you can make the supplier responsible for his system and make him test his component directly."

AZL helps its customers to develop the right test benches that allow them to accurately identify the blocked forces. All of this is an important step to achieve the ultimate goal, which is to pave the way for virtual vehicle assembly.

"The ability to calculate interface forces from the blocked forces is one of the building blocks which enable virtual vehicle assembly," says Schilp. "With this, you could have simulation or test results with blocked forces of systems and combine them together to predict the performance of a virtual vehicle. I believe that with the right hybrid simulation process and reliable test results on system level in place, you can achieve a robust system of down-cascaded objectives certainly for the lower frequency range, up to 500 hertz. And in reverse, if you integrate them up, you will achieve a high prediction quality of your virtual prototype."

The process for component-based TPA is fully supported with Simcenter™ Testlab™ software and the Simcenter™ SCADAS™ data™ acquisition system. It



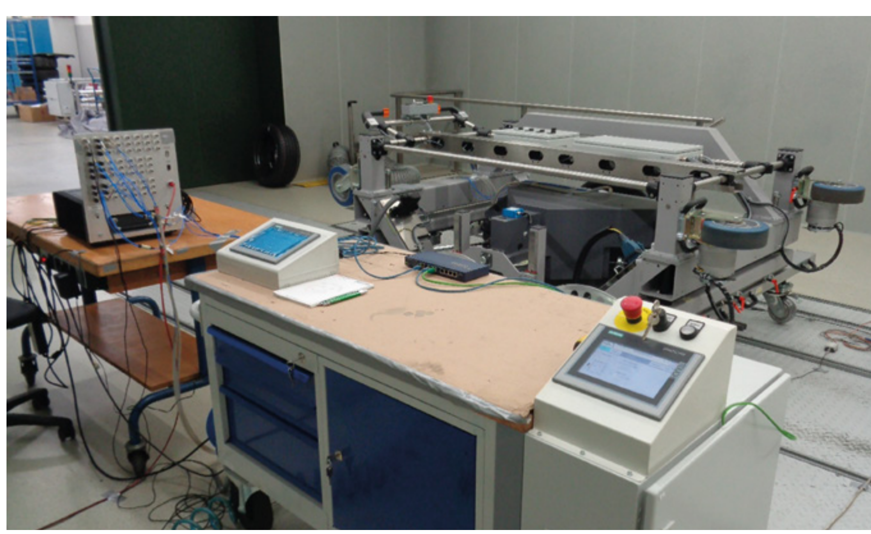
provides an integrated solution for optimal measurement quality of operational and frequency response function (FRF) data and a workflow-oriented analysis tool. This capability helps users to determine blocked forces, convert them into interface forces and make target prediction in a very fast and efficient way.

In demanding applications like component-based TPA data, consistency is essential, productivity-enhancing features have been added like the matrix heatmap which allows users to interpret large datasets in a single click. The display permits instant verification of the data quality and provides tremendous insight into the vibro-acoustic behavior of the different components. Furthermore, the user has many integrated functionalities to verify inconsistencies in the data such as direction errors and reciprocity problems.

Component-based TPA and the conversion of blocked forces into interface forces is fully supported in Simcenter Testlab.

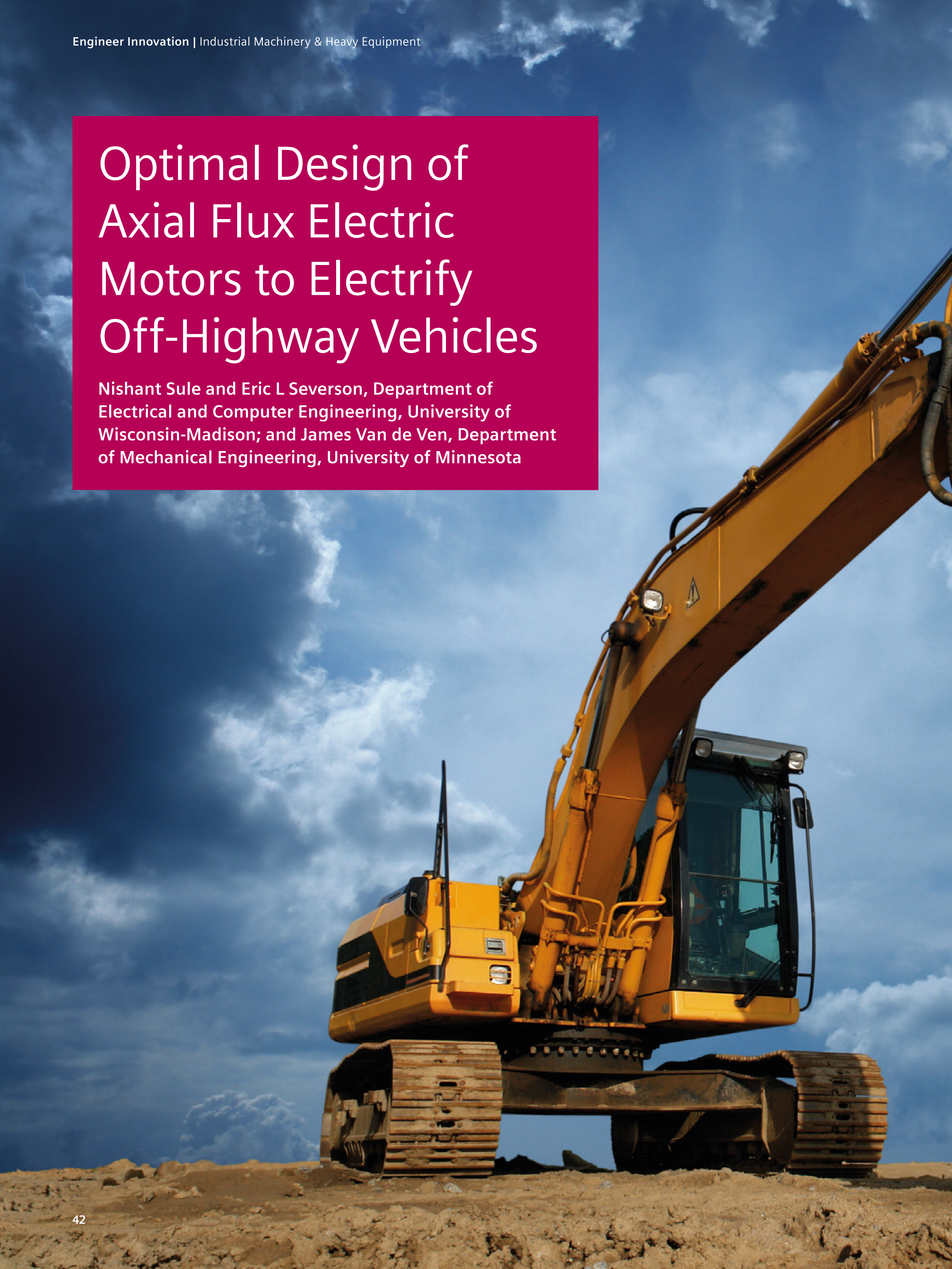
Mastering the road noise
AZL provides an optimized testing environment by developing customized chassis dynamometers with variable surfaces. Additional test rigs called AZL suspension and tire force rigs make it possible to test full vehicles, front and rear suspensions and tire-rim combinations on exactly the same excitations. So, the V-model approach is brought to life in a very reproducible environment.

Based on an optimum database of measurement data, test-validated models provide a robust environment for further virtual vehicle development. ■



Optimal Design of Axial Flux Electric Motors to Electrify Off-Highway Vehicles

Nishant Sule and Eric L Severson, Department of Electrical and Computer Engineering, University of Wisconsin-Madison; and James Van de Ven, Department of Mechanical Engineering, University of Minnesota



Mobile machine equipment such as excavators, backhoes, and skid steers are broadly referred to as off-highway vehicles. They are an indispensable part of several industries including construction, agriculture, and mining, and represent a significant portion of global energy consumption and greenhouse gas emissions. Traditionally, off-highway vehicles are powered by diesel engines. The engine drives a hydraulic pump that distributes fluid power to remote actuators which are responsible for everything from vehicle propulsion to controlling the implements. These hydraulic actuators are controlled by throttling the hydraulic fluid flow, leading to low system efficiency over a drive cycle. A recent study [1] shows that the efficiency from the engine shaft to implement in an off-highway vehicle is approximately 20 percent. In addition, concerns over emissions are driving a movement to downsize or completely ban combustion engines in several countries. Electrification offers a potential solution to both challenges.

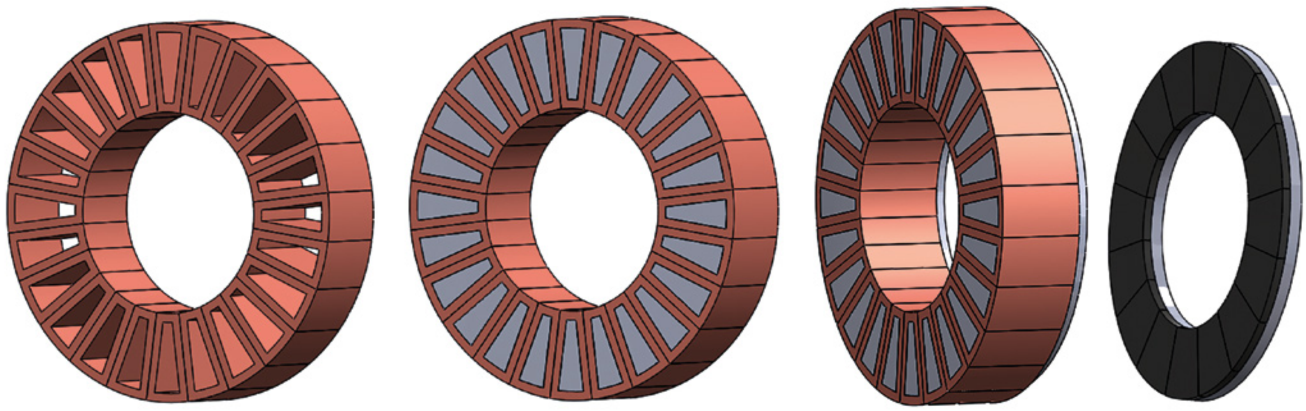
Electric machines can efficiently control actuators by operating fixed displacement pumps at variable speed to eliminate throttles. They can allow the engine to operate at a nominal speed-torque point that reduces emissions. Further, when paired with a battery, electrified off-highway vehicles have a tremendous potential for energy recovery due to their highly transient and repetitive drive cycles [2-3]. While electrifying these vehicles offers a compelling value proposition, the challenges involved are daunting. Electric motors are not as power dense as combustion engines and hydraulic components. This issue is worsened by the highly transient drive cycles requiring the motor to be significantly oversized. Further, the hostile operating environment (high temperature, dust, and dirty air) introduces reliability challenges for the electric machine and drive electronics. These factors together pose a different set of challenges than is found in electrifying passenger vehicles.

A hybrid hydraulic electric architecture (HHEA) is proposed in [2] to overcome the power density challenges of electrification. In the HHEA, the actuators are powered by hydraulic pressure rails, pressurized by a combustion engine. Electric motors with integrated pumps replace hydraulic throttles, to buck/boost the hydraulic pressure to each actuator. The electric motor power rating is minimized by having the combustion engine provide multiple hydraulic pressure rails to which the integrated motor-pumps intelligently connect to best meet the load requirement. A system with more pressure rails requires the motor-pump to provide less bucking/boosting, and therefore less electric power. Thus, the HHEA can leverage efficient controllability that electric machines offer, while retaining most of the power density of hydraulic components. For this architecture to be successful, it is critical to maximize the power density of the electric machine to utilize fewer pressure rails and better support regeneration.

In this article, we present design optimization of an electric machine for integration with a hydraulic pump to hybridize an actuator in a 20-ton excavator. The electric motor rating is determined to be 20 kW at 15,000 RPM. The hydraulic pump is a radial ball piston pump. More information is provided in [3], which demonstrates the advantage of the axial flux PM machine (AFPM) for this application. Our project targets a power density over 5 kW/kg and efficiency over 85 percent for the integrated hydraulic pump, electric motor, and power electronics. This translates to a power density of 9.5 kW/kg and efficiency of over 93 percent for the electric machine. This power density value resides near the upper limit of values reported in the electric machines' literature [4], making it quite challenging.

Design optimization:

In this study, we considered the following AFPM design variants (shown



(a) (b) (c)

Figure 1: AFPM Topologies: (a) Coreless stator; (b) YASA stator; (c) Single rotor stator (notice the stator yoke located on the right axial surface); (d) PM Rotor.

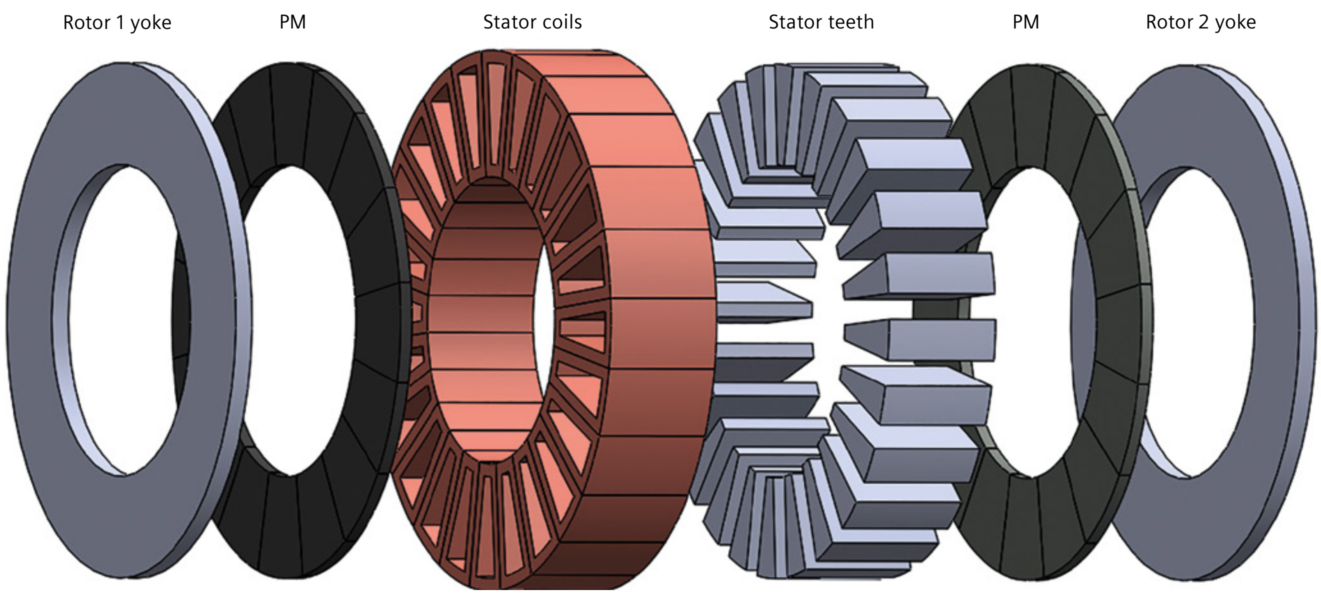


Figure 2: Exploded view of the YASA AFPM

in figure 1): a coreless machine, a yokeless and segmented armature (YASA) machine, and a single rotor-single stator (called the single rotor machine). Exploded views of the YASA and single rotor machines are shown in figures 2 and 3. For the integrated hydraulic-electric machine, the rotor moment of inertia and gravimetric power density are critical to achieving fast transient response and compact form factor. An analytic sizing framework was constructed, that compares the three design variants based on these parameters and subject to the constraints of the hydraulic pump. We converged to a rated speed of 15,000 RPM, based on a compromise between the mechanical challenges, hydraulic pump losses and the power density.

At these ratings, the single rotor machine required only half the PM material of the YASA machine (and approximately one-fourth that of the coreless machine). Therefore, it is at a significant advantage in terms of inertia, cost, and power density. However, the single rotor machine can experience significant axial force between the stator and rotor. While this may have tipped the scale in favor of the YASA machine, in this application the expected axial magnetic forces are within the ratings of the bearings for the hydraulic pump. Therefore, the single rotor AFPM is a clear favorite.

The multi-objective genetic algorithm was used to search the design space for the single rotor axial flux machine. The following optimization objectives were selected:

- O_1: Maximize gravimetric power density [kW/kg]
- O_2: Maximize efficiency
- O_3: Minimize torque ripple

We developed scripts that link MATLAB® optimization toolbox to Simcenter™ MAGNET™ via scripting interface. The optimization algorithm selects a set of geometric dimensions that completely define a machine design. Our scripts then use Simcenter MAGNET to evaluate the machine's performance.

The multi-objective genetic algorithm requires evaluation of a very large number of motor design candidates, making it essential to quickly evaluate FEA models. AFPM feature 3D flux paths, meaning that their complete physics can only be captured with 3D FEA models. Unfortunately, compared to 2D models, 3D models require significant computation time, which is prohibitive for optimization. So, we adapted a 2D FEA technique for model evaluation. A detailed description of this technique is presented in [3]. As the number of computational slices used in the 2D model increases, the performance obtained using the 2D models tend towards that obtained from a 3D model as shown in figure 4. The number of computational slices used is a compromise between accuracy and evaluation time. A 2D model for a 16 pole, 24 slot single rotor machine is shown in figure 5.

Optimization Results:
The optimization was run for 150 generations with a population of 75 per generation. The 2D projections of pareto fronts from the final generation (shown in figure 6) indicate a clear trade-off between the gravimetric power density and efficiency.

Typical PM motor designs reported in literature for passenger electric vehicles have maximum power density of approximately 3 kW/kg while high performance motors used in aircraft electrification reported up to 10 kW/kg [4]. The optimization results in figure 6 clearly show that the single rotor AFPM machine that we are developing can potentially achieve power density well

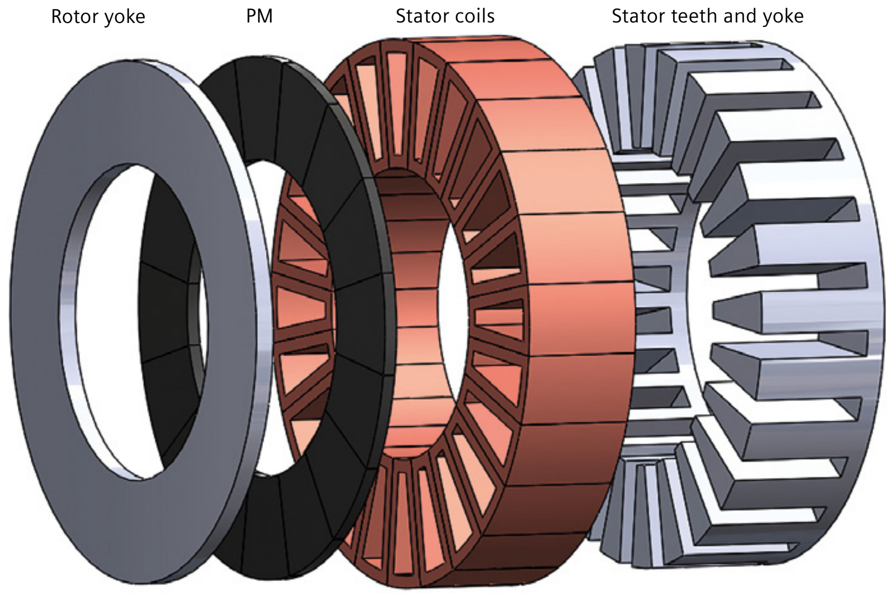


Figure 3: Exploded view of the single rotor AFPM

beyond 10 kW/kg. Several pareto optimal designs shown in figure 6 meet our target performance requirements (power density > 9.5 kW/kg and efficiency > 93 percent). Thus, the design optimization results demonstrate the potential for the single rotor AFPM to meet the performance requirements of the off-highway vehicle. Further investigation details of the integrated system performance and multi-physics optimization will be reported in future publications.

Acknowledgement:
This material is based upon work supported by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy (EERE) under the Award Number DE-EE0008384.

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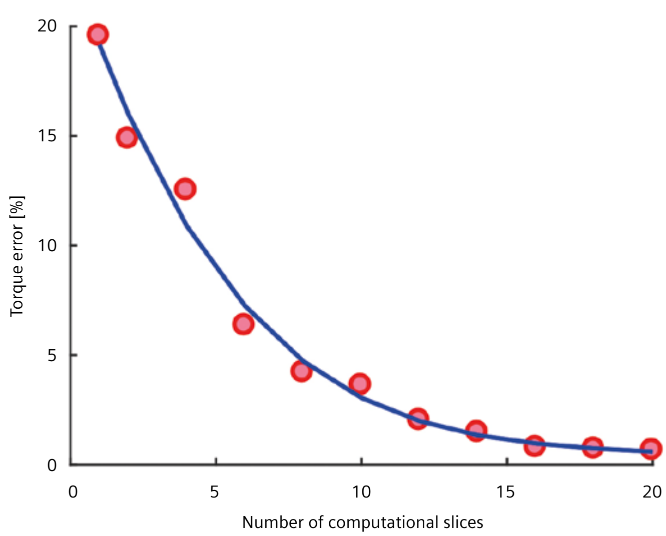

Figure 4: Error in average torque from 2D model as a function of number of computational slices. The torque from 3D model is taken as reference.

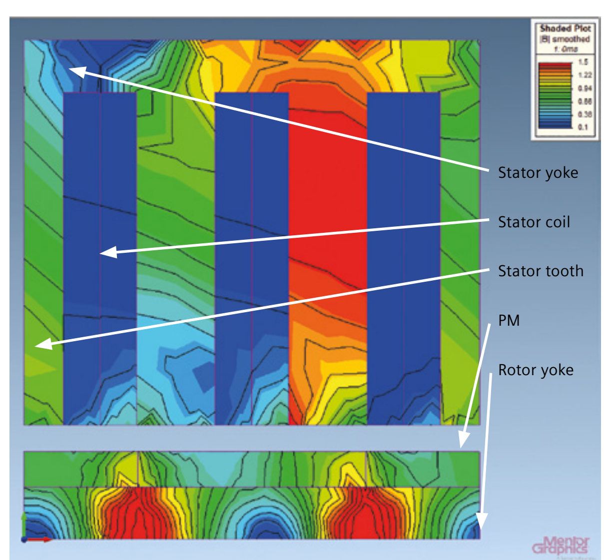

Figure 5: 2D equivalent model of a single rotor AFPM

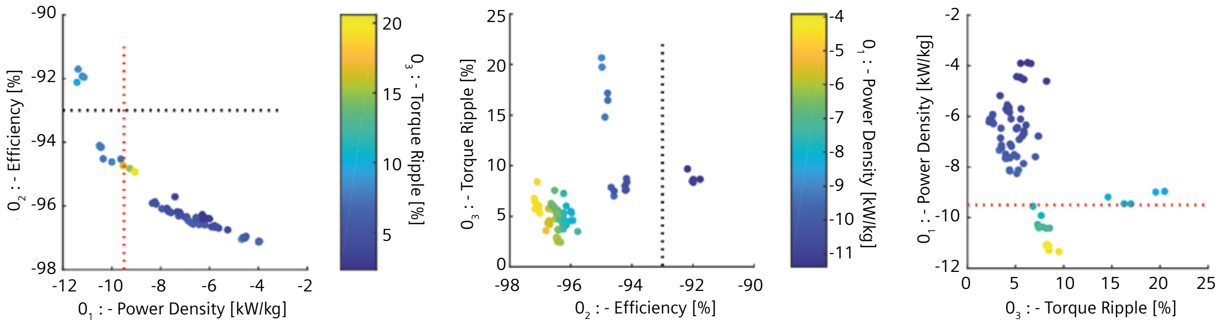

Figure 6: Pareto front projected onto different 2D surfaces. The dotted lines indicate design targets.

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Early design and optimization of a datacenter, a one-dimension approach

By Dr. Azita Soleymani, Director and David Lew, Engineering Consultant, Electronic Cooling Solutions Inc.

Electronics Cooling Solutions Inc. (ECS), based in Santa Clara, California is a dynamic Silicon Valley consulting company. ECS has provided thermal management expertise to the electronics industry for over two decades. The team at ECS use state-of-the-art simulation and measurement tools such as Simcenter™ Flotherm™ XT and Simcenter hardware, they employ design and analysis methodologies that can be scaled to address emerging thermal challenges. ECS have turned their expertise to the optimization of datacenters using 1D CFD tool, Simcenter Flomaster.

Removing the dissipated heat generated is one of key considerations in the design of a datacenter as it is directly related to the reliability, performance, cost, and footprint of data centers. There are different cooling strategies depending upon the power capacity, local climates and the footprint limitations.

The design of a datacenter requires the proper selections of pipes, pumps, valves, heat exchangers and controllers to deliver the proper amount of flow to the devices so that cooling of servers, storages and switches is achieved and optimized.

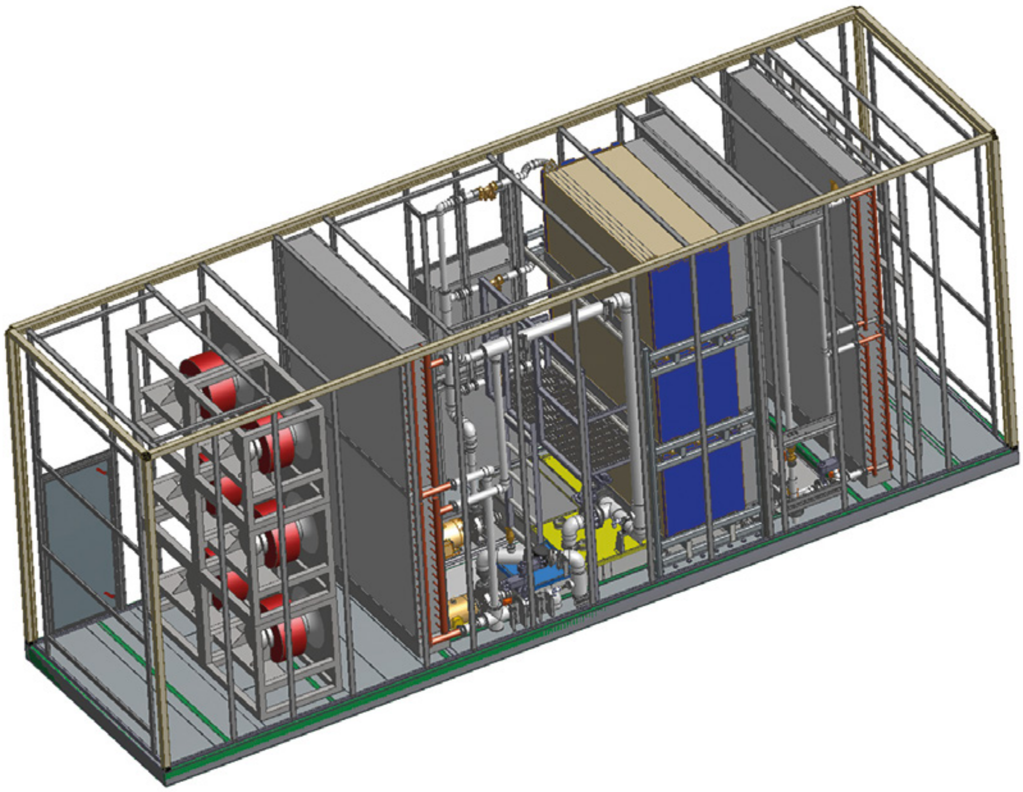


Figure 1: The schematic drawing of the StatePoint unit. Photo courtesy of Nortek Air Solutions.

Developing a system level simulation tool to accurately predict the real-time hydraulic and thermal performance at component and system level is crucial at the very early stages of the design. The tool can be used to evaluate different design scenarios, to evaluate the feasibility of a design, to estimate the energy consumption and water losses, and to size the components such as pumps, valves, heat exchangers and reservoirs. Moreover, the simulation tool can be utilized to perform what-if design /operating scenarios and to conduct in-depth root cause analyses, to further optimize the design and operating parameters.

In this study, Simcenter Flomaster was used to develop a simulation tool to study the real-time hydraulic behavior of a multi-story datacenter, one of the largest datacenter in the world. Three loops are employed : one loop unique to each floor to cool the load of that floor (servers, lights, air conditioning for

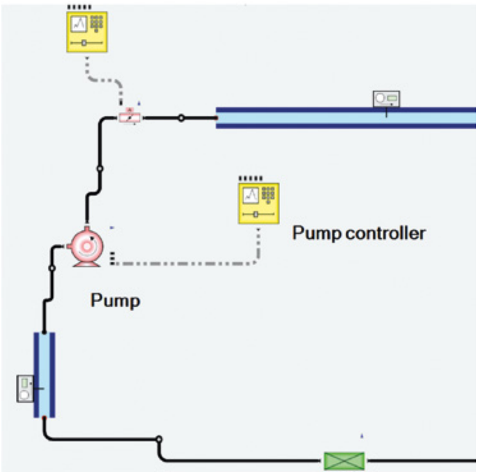


Figure 2: A controller was coupled with the pump to adjust the speed of the pump.

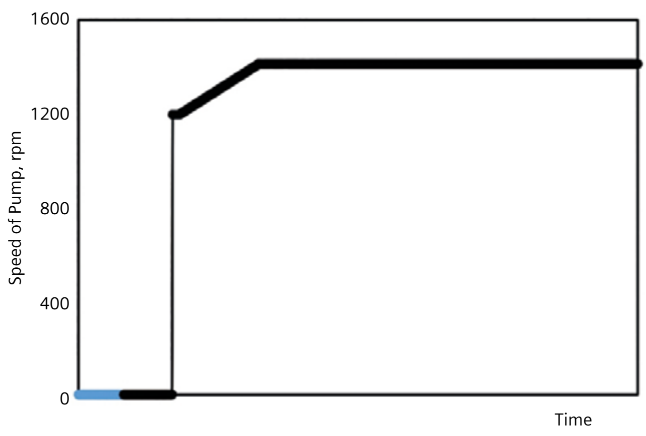


Figure 3: The pump rotational speed as a function of time

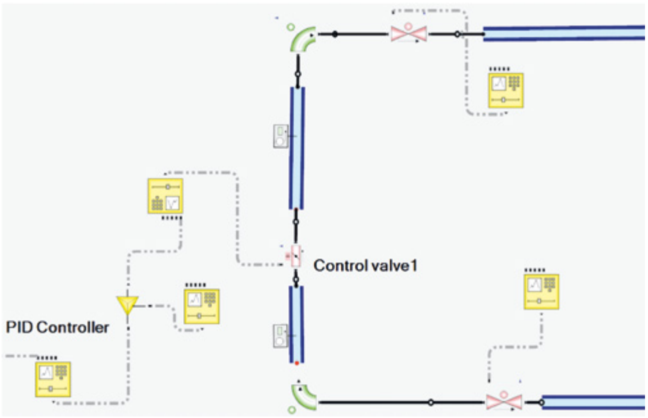


Figure 4: PID controllers were included in the model to modulate the valve openings

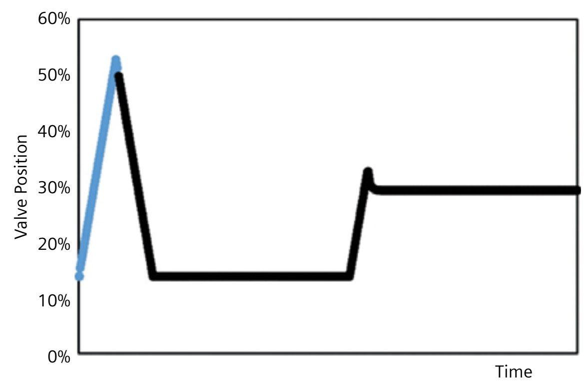


Figure 5: The valve opening is modulated by a PID controller

comfort, etc.); a second loop, running between floors to collect and transport the heat of all the floors to the third loop, which rejects all the heat to the environment.

The preliminary layout and the system sketch, the design goals and the boundary conditions were known. Various operating modes of the data center, including how the system responds in the event of a failure of a critical component, require as many as ten scenarios to be modeled.

StatePoint Liquid Cooling system, a new evaporative cooling system with a registered trademark of Nortek Air Solutions, was deployed. The schematic drawing of the StatePoint unit is depicted in figure 1. In the StatePoint unit water is used to indirectly cool data halls. StatePoint unit operates more efficiently and can be deployed in a wider range of environmental conditions (hot and high humid climate) as compared with other indirect cooling systems. It is expected that the StatePoint systems reduce the water consumption usage by more than 20 percent for data centers in hot and humid climates and by almost 90 percent in cooler climates, in comparison with previous indirect cooling systems. The StatePoint unit can operate in various stages of cooling to optimize water and power consumption, depending upon outside air and process

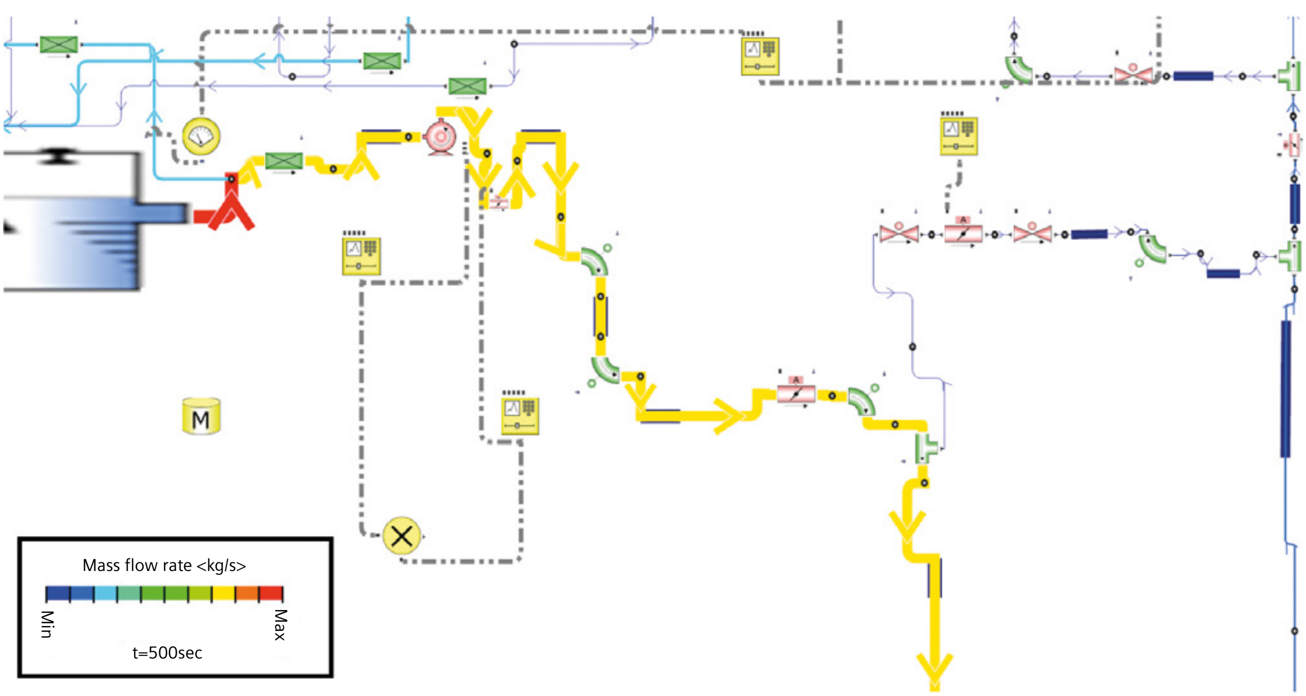


Figure 6: The contour map of mass flow rate of water in the discharge pipe.

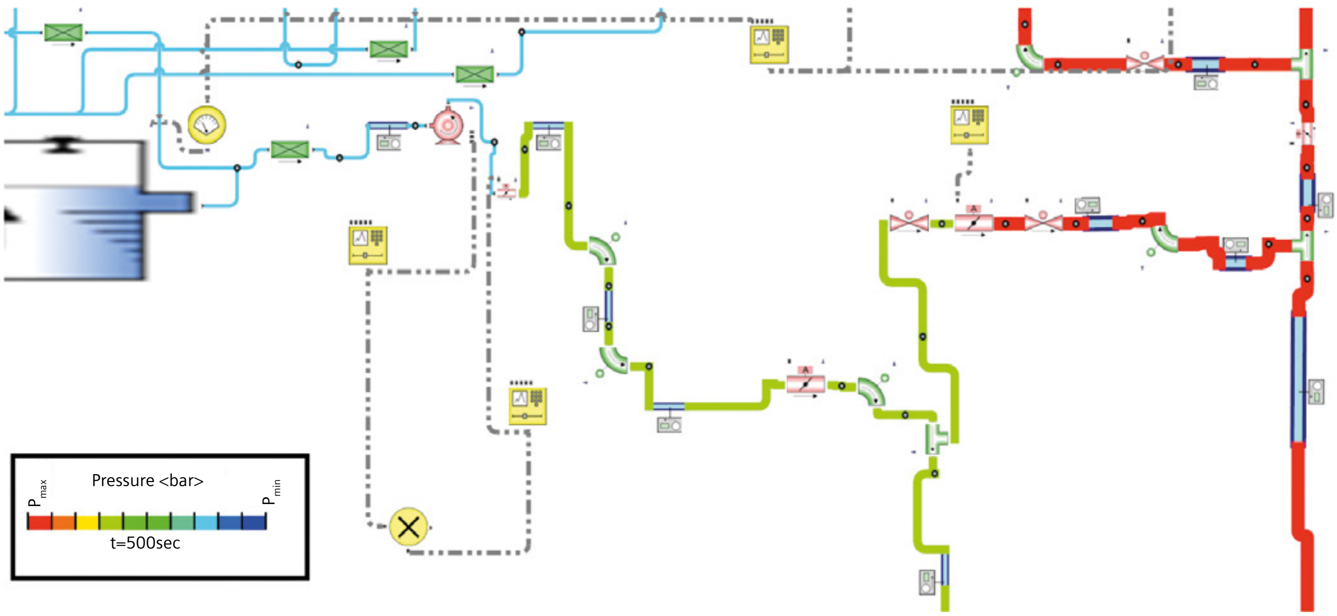


Figure 7: The water pressure at one instant in time

water conditions. The StatePoint unit automatically stages up and down between the Stages of Operation based on selected efficiency mode and inflow water temperature.

The sequence of the operation was implemented in the 1-D simulation tool by writing the scripts and incorporating control features available in Simcenter Flomaster. The temporal variations of the pumps speed, as shown in figure 2 as a function of the reservoir water level, stage of cooling, time, requested speed by the Data Hall Manager and the designed ramp up/down speed was included in the model. Figure 3 demonstrates the temporal variation of the pump speed. The color indicates the operation modes of the StatePoint unit.

Sufficient PID controls, as shown in figure 4 were added to the model to modulate the valves' opening based on the real-time variables such as reservoir water level, pressure drop across a component or a target mass flow rate. The appropriate values for the proportional, integral, and derivative modes for the PID controllers were estimated using Ziegler–Nichols tuning method.

The model results can be used to size pipe diameters, bend radius, pumps, and heat exchangers. The results can help to identify if there is sufficient capacity for growth, and to determine whether redundant systems should be considered for high reliability, or whether the risk without redundancy is acceptable. At the very early stage of the design, model results can be used to identify opportunities for minimizing the overall pressure head losses within the datacenter. Furthermore, the model results can help answer questions on future occupancy (five to seven years down the road) and commissioning issues (system isn't responding as expected). ■

"StatePoint systems reduce the water consumption by more than 20 percent for data centers in hot and humid climates and by almost 90 percent"

Dr. Azita Soleymani,
Electronic Cooling Solutions Inc.

Seeking continuous improvement at Briggs & Stratton

Small-engine manufacturer uses Simcenter Testlab and Simcenter SCADAS to achieve product goals early in the development cycle

Every day, engines are used for all sorts of tasks. From constructing a building, providing power to a clinic during an outage, watering rice fields or simply making the lawn look great, engines are at the heart of it all.

Briggs & Stratton is an American manufacturer of small internal combustion engines with its headquarters in Milwaukee, Wisconsin. The company's engines are sold in over 100 countries across the globe. Briggs & Stratton engines are most commonly used for lawn mowers, lawn tractors, pressure washers, water pumps, generators and a variety of commercial applications, such as aerators and concrete trowels.

To stay on top of their business, the engineering department is continuously improving engine models and developing new engine families to expand market share and enter into new markets. Its noise, vibration and harshness (NVH) lab is responsible for ensuring that sound and vibration levels are the best-in-class, and that the durability of their products exceed expectations.

Achieving goals early in product development

The Simcenter SCADAS hardware data acquisition system and Simcenter Testlab software play an integral role in the work of the NVH lab, providing engineers and technicians with a process that enables them to achieve product goals early in the development cycle. The NVH lab consists of a small group of engineers who are experts in the field of NVH and durability. The testing lab currently has four Simcenter SCADAS systems. Two of them are used for acquisition in hemi-anechoic sound chambers and the other two are applied to portable measurements in lab and field conditions.

The engine sound pressure is measured, and the sound power and quality are calculated using Simcenter SCADAS, which is in the control room. Simcenter Testlab is used to monitor live data and processes during the recording, saving testing and postprocessing time during analysis. Simcenter test templates are created for both sound and vibration measurements and are now more easily documented. This improves testing capabilities and ensures common procedures for all the employees in the NVH lab.

Brett Birschbach, senior engineering manager, NVH and durability, comments, “I can’t tell you how many times an engineer has looked over at me and said, ‘This software is really easy to use!’ This is far easier than what we had before because it’s just more flexible.”

“With Simcenter Testlab, the data is in the tree, you drag it over, drop it on and you have the data visualized and can easily compare it to older projects,” says Brett Weed, test engineer in NVH and durability.

Matching design to quality standards

When working with engines, noise level is a primary concern. In Europe, for example, there are multiple certification standards for vibration and pressure-based sound power. Spectral analysis, sound power and quality metrics are considered from the start. The NVH lab engineers looks at the noise sources in their products and adjust the design to match quality standards.

At the Briggs & Stratton testing facilities, most products are tested on concrete, however, they also utilize artificial grass for testing lawn mowers. They also test on load banks – horizontal or vertical, with different speeds and loads – to

mimic loading conditions on the applications, as well as to measure the sound the customer is going to hear. The NVH team holds jury testing to determine which sounds are more pleasing to customers.

These types of noise measurements also allow them to perform noise labeling according to the market directives. The NVH team relies on accurate measurements to certify the quality of the products. "We want to be best-in-class in noise and vibration, so we use Simcenter solutions to do the work," says Birschbach.

Correlating sound and vibration
Engine and application vibration are also recorded using Simcenter to help identify noise sources related to vibration. The engine vibration is measured on an isolated test stand for engine development and auditing using the Simcenter SCADAS data acquisition system. Simcenter Testlab makes it easy to correlate the application sound and vibration and analyze the data to improve them.

"I use Simcenter throughout all my testing; from the beginning of the measurement to the end processing," comments Weed.

Vibration and strain are also measured on applications undergoing typical field use. Both vibration and strain are measured with Simcenter tools and the recordings are applied to the accelerated

testing of engine and finished product. Simcenter SCADAS XS hardware is a portable acquisition equipment system well-suited for these types of measurements. For example, it is important to measure the handlebar vibration of a lawn mower caused by the engine for safety and comfort, making sure it meets guidelines such as the International Organization of Standardization (ISO) 2631 human body vibration standard.

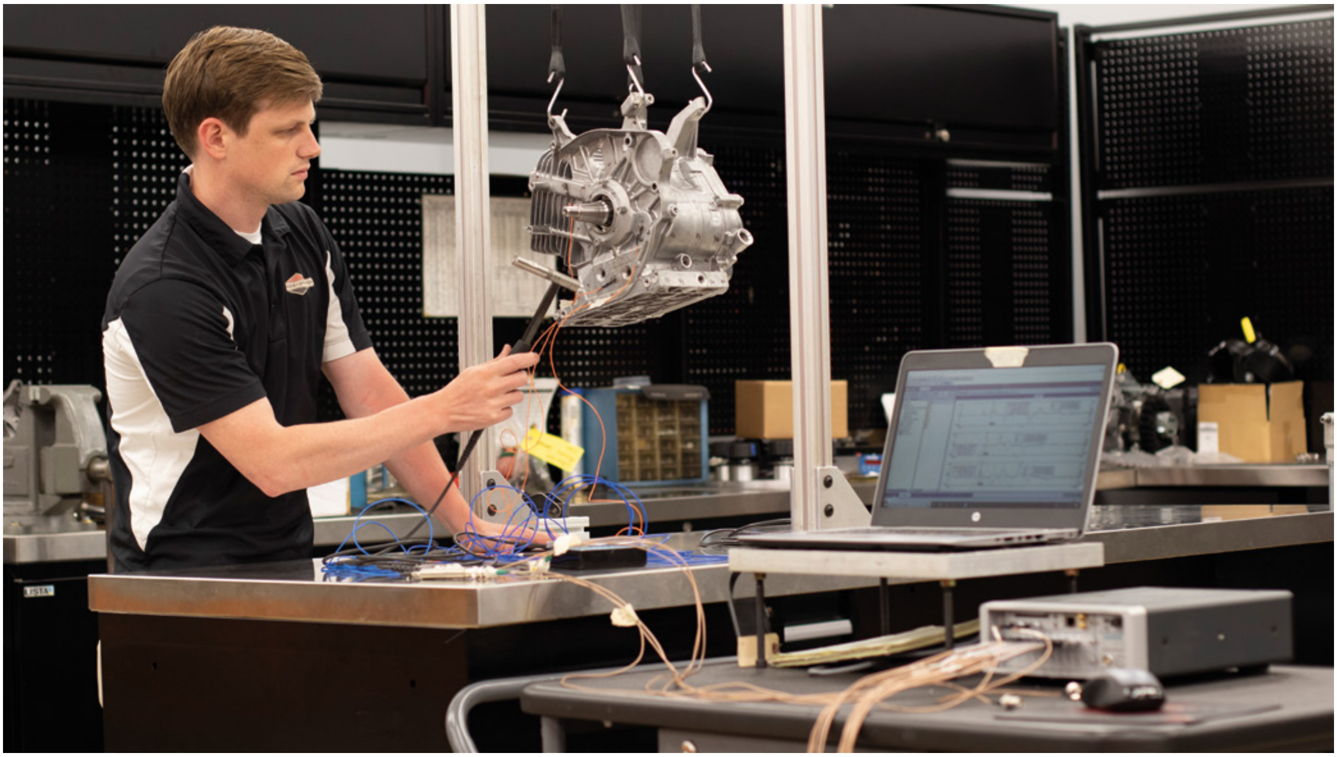
Providing durability

The same equipment is used for durability testing. The data acquired with the system can easily be converted for use on accelerated tests using a shaker or a hydraulic test system. The NVH lab uses strain gauges and fatigue damage spectrum for their accelerated tests. Modal testing is performed using a shaker or a hammer impact on engines and products in the NVH lab with Simcenter testing solutions. The hammer and shaker modal setup in Simcenter Testlab is easy to use and delivers an accurate and repeatable presentation of results.

The processing tools that Simcenter offers provide engineers with the ability

"Simcenter Testlab is easy to use and delivers an accurate and repeatable presentation of results."

Brett Weed
Test Engineer in NVH and Durability
Briggs & Stratton Corporation



"We want to be best-in-class in overall sound levels, so we use Simcenter solutions to do the work."

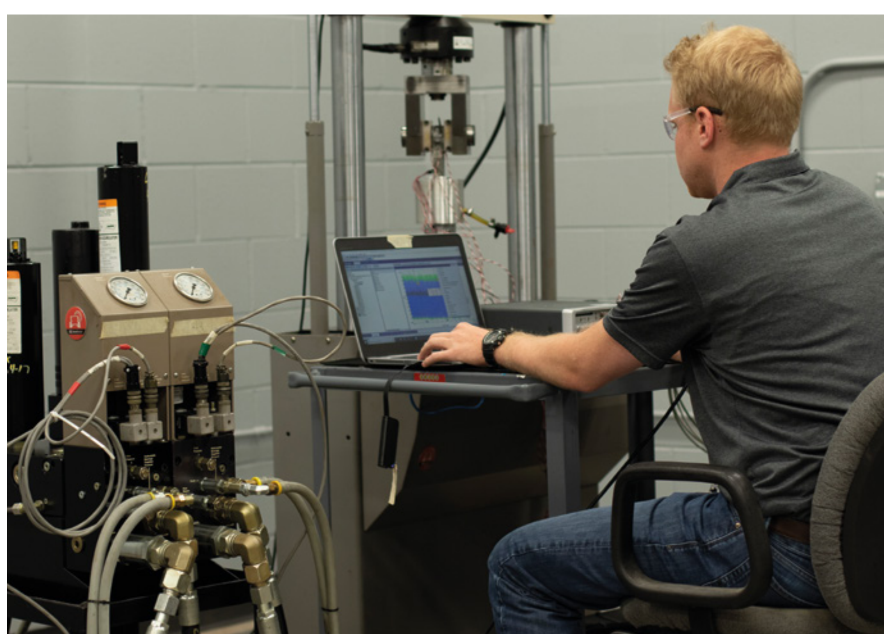
Brett Birschbach
Senior Engineering Manager, NVH and Durability
Briggs & Stratton Corporation

to evaluate the engine vibration responses in determining the optimum balance and identifies areas for improvement at the component level, providing a durable product.

Briggs & Stratton's 200 Vanguard (VG) horizontal engine is an example of this. The 200VG is sold in the commercial market and requires high standards for reliability, ease-of-use and operator comfort.

The advantage of flexibility

For Briggs & Stratton's NVH test and research and development (R&D) engineers, switching to a token-based licensing strategy proved to be quite beneficial. Simcenter Testlab tokens are a flexible licensing mechanism that gives users access to a large library of software modules for doing testing and data analysis. Unlike fixed item licensing, in which only specifically purchased licenses can be used, the Simcenter



Testlab token licensing option allows users to run any combination of token-enabled software modules.

Every problem is different and requires different tools, and with the token system, all tools are at hand.

“One of the things we like about Simcenter Testlab is the token-based licensing,” says Birschbach. “It opens up a whole world of possibilities. It allows us the freedom to do different analyses when we need to. If we want to do modal analysis one day and durability life prediction the next day, and if we need to do sound quality analysis after that, we can! I'm not forced into buying individual software. That flexibility was huge, as we are a relatively small NVH group.”

Siemens' support has also been facilitating testing for engineers at the Briggs & Stratton NVH lab. As Birschbach comments, “Support is critical for a company like ours, and our support experience with Siemens has been exceptional. The level of support you get is remarkable. You not only get support immediately on the call, but if the issue cannot be resolved right away, you are going to have a solution as soon as possible. And not only for problems; if we have any questions, we can always call and they will give us advice, which has been very helpful to us.”

The Briggs & Stratton NVH lab plans on extending their capabilities in the future by implementing new features offered by the Simcenter portfolio in their testing to achieve consistent power without the noise. ■

Cox Marine revolutionize the outboard engine industry

British startup Cox Marine ready to revolutionize the outboard engine industry thanks to digitalization

Changing the game for outboard engines

The massive, market-changing advantages of a high-powered, fuel-efficient, cleaner V8 diesel outboard engine are obvious to salmon farmers in the Norwegian fjords or islanders in the Maldives who drive Zodiac boats to work. For Joel Reid, these advantages are front of mind.

Reid is the global sales director of Cox Marine, a British startup based in Shoreham-by-Sea, near Brighton, UK. A company with a serious desire to change things for the better, Cox Marine knows a business opportunity when it sees one – and knows how to act fast. This was the case with its first product, the CXO300 outboard engine, which is packed with punch yet 25 percent more fuel efficient and cleaner than most other outboards in the global marine industry.

Specifically designed for the marine industry, the CXO300 is set to go into production in late May 2020. One of the most powerful diesel outboards on the market, this high-performance 300 horsepower engine promises to last three times longer than comparable models. And Cox Marine has more ideas up its sleeve.

"Our CEO Tim Routsis likes to say, 'We are not developing a product; we are developing a business.' And this is by far the biggest challenge that we face," explains Reid.

Cox Marine didn't plan to just offer a dedicated marine engine. They also set up a global service network of 200 dealers and representation in 100 countries. And while they reinvented the marine outboard engine, why not reinvent the service model as well? The company aims to redefine the standards of global service and customer care including cloud-based data analytics services,

such as engine performance statistics, revenue savings, real-time maintenance information and other predictive diagnostics.

"We were able to build a much bigger and comprehensive organization to deal with the mammoth task of not just developing a diesel outboard as a product, but also developing an organization that can manage global demand, global services and volume manufacturing," adds Reid.

The choice for diesel

In this day and age, the conscious choice for diesel might seem strange to some. But high-performance diesel offers numerous advantages to the marine community. One, it eliminates the burdensome and sometimes messy practice of self-mixing the right gas/oil ratio, a requirement for classic two-stroke outboard engines. Secondly, diesel is cheaper, more readily available and far less combustible than gasoline. And, diesel offers better fuel performance, which means significant bottom-line savings for price-sensitive operators with high hour usage ratios. (Think of the aquaculture farmers in Norway or an offshore rig that transports staff back and forth daily.)

"With our engine, you get the fuel savings of an inboard diesel engine combined with the lower risk of an outboard engine," Reid says. "Downtime is a very important aspect for many customers. If they can't operate, they can't make money. Diesel engines are dependable workhorses. And, if worse comes to worse, you can swap an outboard engine or transmission. It is much easier to repair than an inboard. This is why our diesel outboard concept is so appealing to broad segments of the market. I can't see anybody who wants to go fast with a 300-horsepower requirement that wouldn't want our product."

Designing it right

The bigger commercial picture aside, creating a bespoke, horizontal V8 engine for the marine market requires a high level of excellence when it comes to engineering. Excellence is in the heart and soul of Cox Marine. It all started in 2007 when motorsports racing engineer David Cox came up with the idea to develop a lightweight diesel outboard using Formula One® (F1) technology. Charles Good joined as chairman and this idea was extended to the diesel outboard market the next year. When the first concept engine was fired up in 2010, Cox Marine was still a very small

team of four or five people. Over the next few years, the team worked on the alpha and beta engine versions in partnership with Ricardo. In 2014 the current CEO, Tim Routsis, a former Cosworth executive and a serious racing insider, joined the company and started to push Cox Marine into the market as a global player.

Over the next five years, engineers and experts from all types of fields from marine and automotive to motorsports and aviation joined the team. Everyone shared a single credo: a passion for fast engines and the belief that Cox Marine could change the marine industry for the better.

Translating this passion and vision into a high-performance reality posed many technical challenges, and getting it right was mission-critical.

"We had to make something as small and light as a car engine, but as strong and robust as a big truck engine. Software plays a huge role in understanding how to optimize and design structures. There are so many elements to consider," explains Reid. "Digitalization for Cox Marine is the opportunity to stand out in the crowd."

Enter the game-changer: digitalization
And digitalization is where tools from Siemens Digital Industries Software enter the picture. Specifically, the team relies on digitalization tools from the Xcelerator portfolio, including Teamcenter® software for end-to-end integration, NX™ software for seamless design capabilities and Simcenter™ software for comprehensive digital twin and performance simulation.

"The Siemens tools are used by a large proportion of our staff. We are also using a Teamcenter integration framework to integrate the Siemens platform into our ERP solution," explains Tony Ferrier, head of IT at Cox Marine. "Teamcenter is used by most of our employees. It is at the very core of our business. It holds all our design infrastructure, so it talks to our NX systems. Teamcenter manages all our documentation – all our bills of materials. This information drives the process all the way from design and engineering to our manufacturing process and production facility."

Enter the channel partner: OnePLM
Getting the whole process up and running didn't happen overnight. Cox Marine counted on Siemens Solution Partner OnePLM, a recognized Smart Expert partner, to help implement the right tools at the right time and to bridge the digital backbone and ecosystem into the company's ERP and production solutions properly.

"Our IT systems seem quite complex for a small startup, but as the company grows, it is very scalable," Ferrier says. "We won't need to make any major adjustments in our infrastructure. Looking forward, we can go from making tens of engines per week to making thousands of engines per week if required."

The experts from OnePLM are onsite regularly, making sure that the

"Software plays a huge role in understanding how to optimize and design structures. There are so many elements to consider"

Joel Reid
Global Sales Director
Cox Marine

Teamcenter, NX and Simcenter installations are up to speed and adapted to the growing infrastructure of Cox Marine.

Stability and seamless integration: Teamcenter and NX for the Cox design team

Cox Marine is on the fast track when it comes to growth – the software implementation and the design process run in parallel. Luckily, the design team, led by Julian West, principal engineer, is full of experts from F1 racing, motorsports and aerospace. Like everyone at Cox Marine, they are passionate about designing and engineering things that go fast. The tools that support this team need to be one step ahead of the game as well. Most of the team have solid NX experience, but, especially on the design side of things, implementing the complete Teamcenter and NX backbone changed the way the team worked.

"We have a large product with 6,500 part numbers in the total outboard," says West. "For guys working on big sections all day, just letting the tool do its thing, working all day without constantly crashing or freezing with big assemblies open really is one of the most powerful aspects for us."

Another aspect that the design team appreciates is the seamless integration between Teamcenter and NX. "The best way to explain is that it is practically invisible," says West. "The guys in the team fire up their terminals, fire up Teamcenter and fire up NX, open the data they need and get on with it."

West was quick to credit the Siemens tools with keeping its bill of materials complete and accurate. "For the first time in our business history, we have total control over the total content of our bill of materials," West says. "If you have thousands and thousands of parts and you are relying on a team of humans to build something, humans are humans, so you will make mistakes. Since turning on all those fancy tools like change control, the vast majority of errors have gone away."

Confidence in the digital twins

Like many high-end engineering environments, there is an air of friendly competition between the design and engineering teams at Cox Marine.

Managed by Euan Freeman, a long-time aficionado of Simcenter™ Amesim™, the advanced engineering team has played a major role in the success of the CXO300.

The art of the possible with a digital twin

Early in the process, the engineering team at Cox Marine started to create a digital twin in Simcenter Amesim. Today, this has advanced to a co-simulation model between the Simcenter Amesim and Simcenter 3D software packages. This advanced engineering model is critical to all kinds of design decisions. With advanced performance predictions, engineers can quickly try out concepts for feasibility studies. They can model parts to see if they are the most effective. They can tweak the model virtually to see how a design change might affect performance criteria. And they can help the test team troubleshoot issues on the prototype.

"If we can use Simcenter Amesim to simulate something rather than build or 3D model it, we will," says Freeman, principal engineer for systems engineering and fluid analysis at Cox Marine. "It is a flexible tool to turn out quick answers. With Simcenter Amesim, we can potentially get the initial answers in hours or days rather than months."

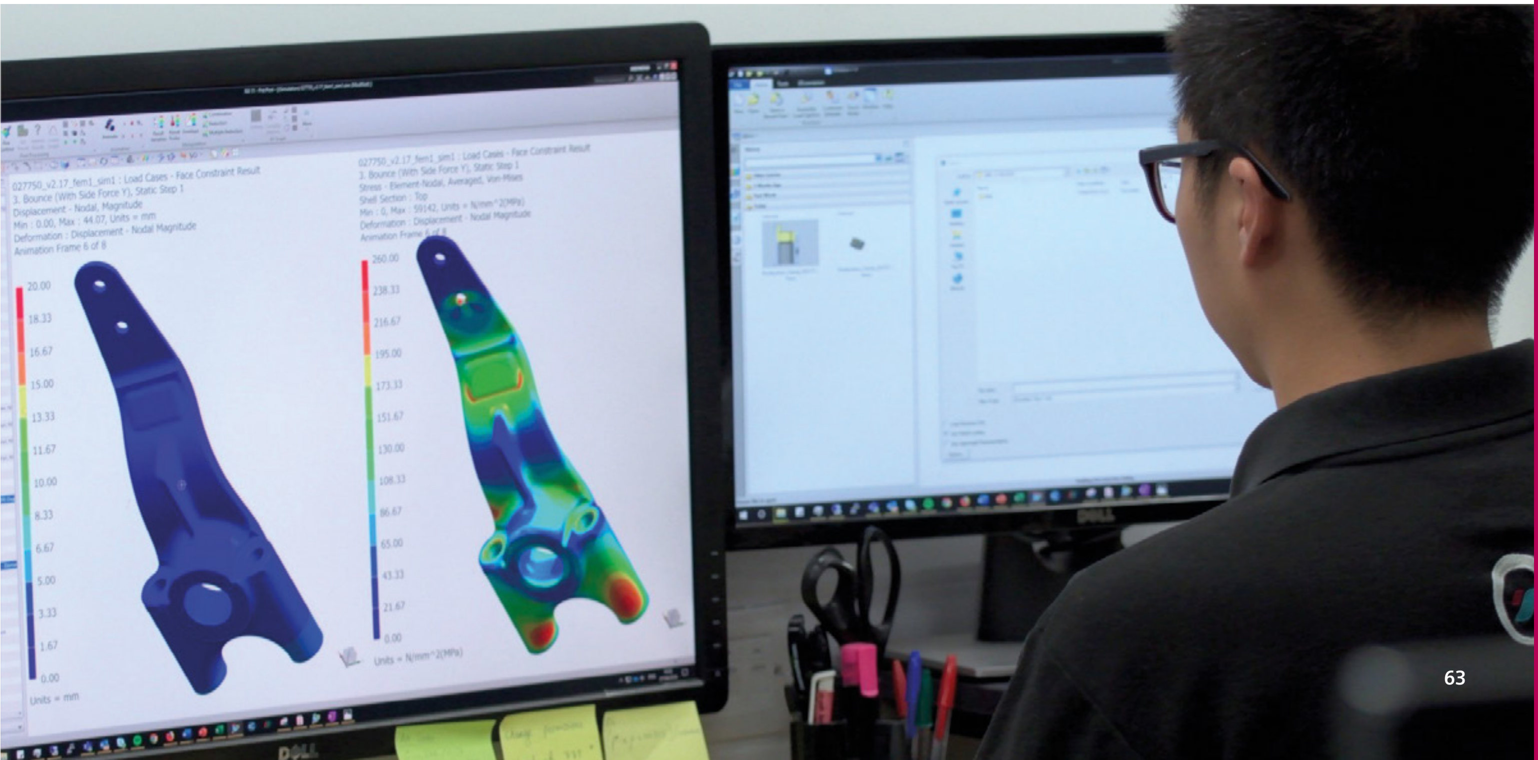
The CXO300 is a massively complicated system and the core job of the engineering team is to balance issues like engine performance, fuel efficiency targets, and emissions. As a startup, getting that first engine on the market is a question of time as well as money.

"We can take out a huge amount of uncertainty in the first build using Simcenter Amesim," Freeman says. "We can do a huge amount of upfront work. We would have 24 variants of engines and have one engine that would have to be built. We're looking at hundreds of thousands of pounds being saved just by doing that upfront. For us, that drives development time down by months and months."

What's next?

As the designers and engineers begin work on the next product release and the test team fine-tunes final performance aspects on the water, everyone at Cox Marine is excited to see the first CXO300 outboard roll off the production lines at the new factory in Shoreham-by-Sea.

"We hope that everyone will be fully convinced that high-performance, fuel-efficient diesel outboards are the way forward," Reid concludes. "This is a journey that we all embark on. We are in this for the long run. We are in this to change the market. You do not change the market with a product. You change the market with a commitment, a service that goes for decades and decades. I think that's what makes us unique." ■



How to...

Predict realistic operational loads and assess fatigue life

By Sebastian Flock – Business developer, Simcenter 3D

Heavy equipment is a considerable investment, an excavator costs as much as a family home and even a small backhoe still matches the cost of a luxury car! An investment like this needs to be one that operators can rely on. Mechanical parts must be able to sustain many mission cycles and potentially unforeseen events, operating on a particularly challenging site or stretching the boundaries within which they were designed. Engineers designing this equipment therefore are seeking to guarantee sufficient operating-life and ensure where possible the vehicle remains safe from damage that can accumulate over the many duty cycles. Consider the repetitive loads acting on the machine - such as the weight lifted and vibrations from maneuvering on rough terrain – challenging conditions!

Excavators can weigh up to 900 tons with a bucket load up to 80 tons for the most extreme mining applications, carrying these loads whilst often subjected to vibrations from maneuvers on inclines or uneven ground. This combination of loads and dynamics imposes significant mechanical forces/ moments on the machine's components. Consequently, identifying weak spots in the structure during the machine design ensures maximum resilience; durability is a top priority for machine makers.

Pinpoint potential weak spots

The engineering process typically involves different domains such as design, systems and mechanical engineering. Based on the initial CAD structure, finite element analysis (FEA) is performed. In order to refine the design and derive realistic operational loads, multi-body simulations of the entire machine are conducted. Finally, based on these loads, fatigue analyses certify the final design.

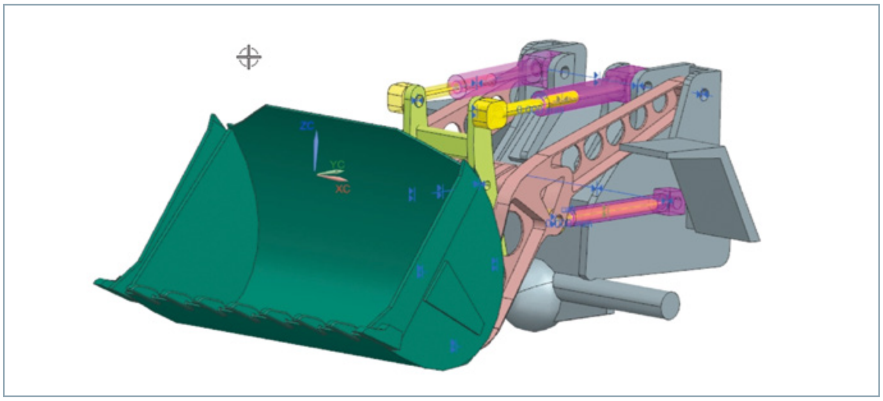


Figure 1: Loader unit with main boom, bucket, and hydraulics cylinders

Here we will take a wheel-loader as an example to demonstrate the process, one of the main mechanical parts of a wheel loader that needs to be efficiently engineered is the loader unit (figure 1).

Providing modeling and design teams with a single platform to access the same data source for both CAD and CAE, enables efficient collaboration. This saves valuable time for both teams with less iteration cycles. Plus, switching from CAD to CAE modeling, enables the engineer to refer to already existing meshed components in the CAE library and automatically update the CAD model.

Once all the parameters, such as loads and boundary conditions, have been set in the CAE 3D simulation environment, structural load is clearly visible and potential weak spots easily identifiable.

Evaluate your design

After the FEA, your next obvious step is to take corrective actions in the CAD design to try to optimize load capacity and change the component geometry. The simulation can be re-run without additional modifications and the results compared to judge the design change. Evaluating a variety of designs based on modification can be time-consuming, when done manually (figure 2).

Now the design can be taken one step further as it is easy to define some design degrees of freedom. Using a Design Space Exploration tool helps engineers to systematically explore variants in order to find the best one (figure 4).

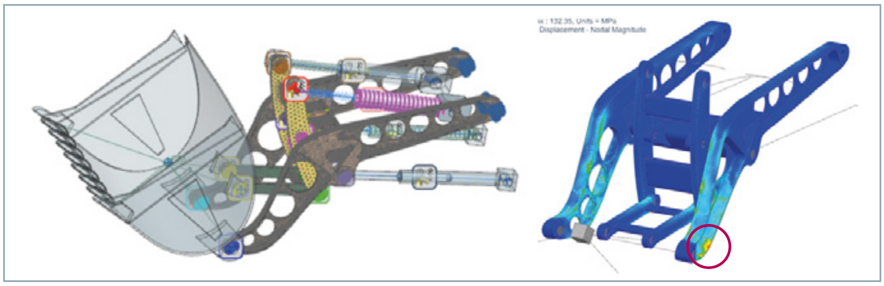


Figure 2: FEM assembly of the loader unit with FEA results for the main boom

Once the structural design of the parts is consolidated the assembly can be analyzed in its entirety with multi-body simulation.

Simulate the full transient mission cycle
From that previous step, the loader unit is assembled within the context of the full vehicle. With simulations of characteristic operations – considering positions, velocities, accelerations – realistic loads can be derived on the individual components, representing the real utilization of the Wheel Loader.

Multi-body simulation considers the kinematics, hydraulic actuation, control system, as well as the relevant structural dynamics (figure 4).

These analyses for operations such as lifting, digging or loading enable answers to critical questions that improve the machine's reliability, such as: What are the critical loading conditions? Which are the peak loads and where do they appear in a load cycle? How do controls and hydraulics influence these loads?

Assess fatigue and derive representative component tests
After having designed the component and understanding the system's interactions over real load cycles, a dedicated durability assessment can be performed. Sufficient analyses and data exists to understand the likely fatigue for the main boom of the loader unit.

From the previous multi-body simulation scenario, information about damage accumulation can be extracted and estimated remaining lifetime for various scenarios. A dedicated durability solver ensures that in the fatigue analyses the correct local stresses are considered for the correct component and the correct external load.

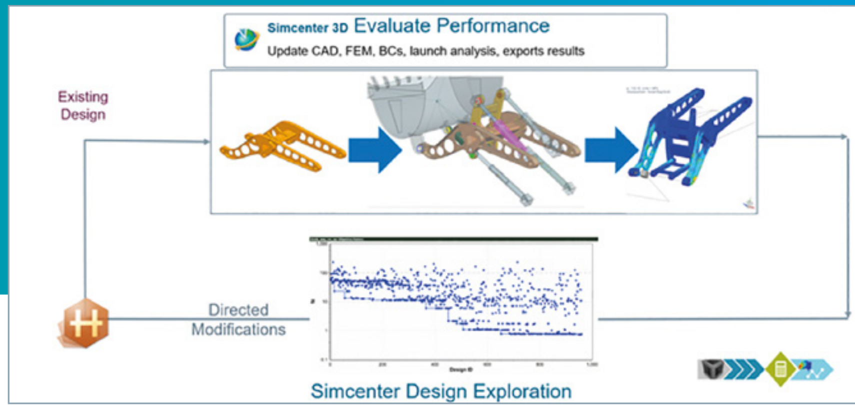


Figure 3: Automated design space exploration based on simulation results

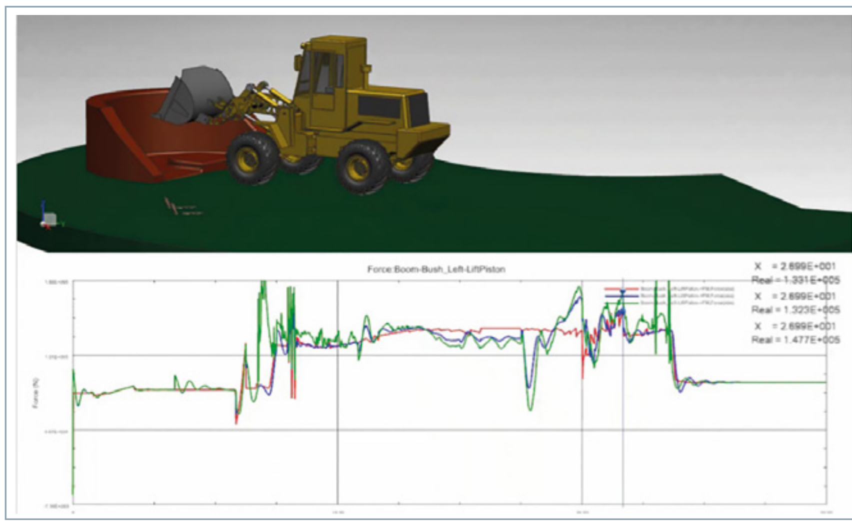


Figure 4: Multi-body simulation results of full duty cycle

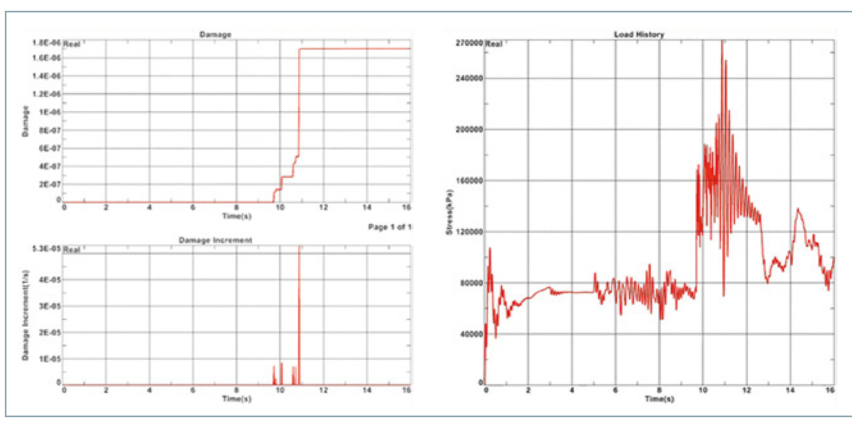


Figure 5: Damage accumulation and transient strain curve

In figure 5 we can see a typical damage accumulation history for the highest loaded location on the main boom of the Loader unit. This can be directly mapped with the transient load history from the multi-Body simulation.

Because we can assess the damage accumulation based on the transient results, the identity of the critical load cycle sub-sections are clear. We know which loads and in which direction are critical for the component. This helps to define test scenarios representative for all relevant loads and dynamics. For example, only a 2-second-long part of the load cycle reflects all potential damage accumulation. With this level of understanding, test durations can be reduced significantly and the setup simplified. ■

Fully-Calibrated Thermal Models Keep Customer Designs Cool

The benefits of Transient Thermal Tests and Thermal simulations for ASE Group and their customers

By H.E. Chen, Ian Hu, and Penny Yang ASE Global, Taiwan; Jay Chien EFD Corporation; and Hon Wong, Siemens Digital Industries Software

The age of 5G is upon us. It promises vast improvements to existing mobile networks, allowing improved connectivity between users, machines and smart devices. Besides benefitting consumers with faster mobile network communications, mission critical communications such as those for autonomous vehicles, robotics, medical equipment and industrial, the Internet of Things (IoT) will stand to benefit too. ASE Group is designing and developing the integrated circuit (IC) packages used in a wide range of applications such as vehicles, smart devices such as smartphones, wearables, smart clothing, augmented/virtual reality devices etc.

Increased functionality and additional features has resulted in the IC packages for these devices to be ever more complex in terms of layout and design. Their power dissipations and overall size has also correspondingly become greater as shown in Figure 1.

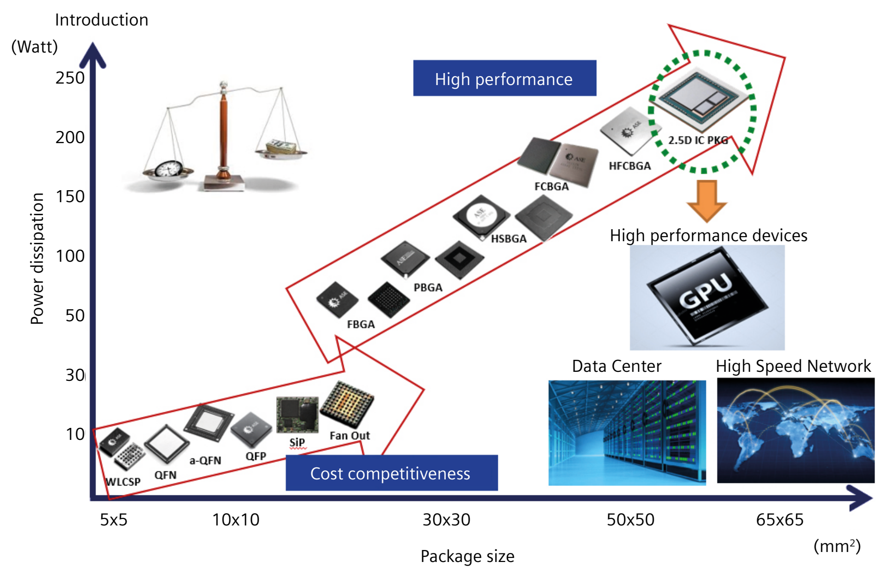


Figure 1: Increasing complexity, size and power dissipation of packages

Traditional workflow

The thermal metrics such as θ_{JA}, θ_{JB}, θ_{JC} and compact thermal models have to be supplied to end customers to assist their design efforts. These system integrators are responsible for board layouts, chassis and cooling solutions for the IC packages designed and supplied by ASE. In the past, 2-Resistor and DELPHI models were supplied, based on the detailed IC package simulation models created in Simcenter Flotherm software. The detailed IC package models were not calibrated against experimental test results prior to creating compact thermal models. The measurement and simulation routes were entirely separate.

The inaccuracy of 2-Resistor models is well known. For example, the model is boundary condition dependent, as it does not take into account changes in the 3D heat conduction within the package. Consequently it is not suitable for all package types.

DELPHI models on the other hand, give greater accuracy compared to the 2-Resistor models. However, this comes at the expense of increased thermal network complexity. The methodology for obtaining the DELPHI models is described in JEDEC standard JESD15-4 and it requires a simulation-based approach, rather than physical tests. So the accuracy of the compact model is compromised by an uncalibrated detailed model.

Besides having to supply accurate compact thermal models to customers, ASE typically needs to carry out design

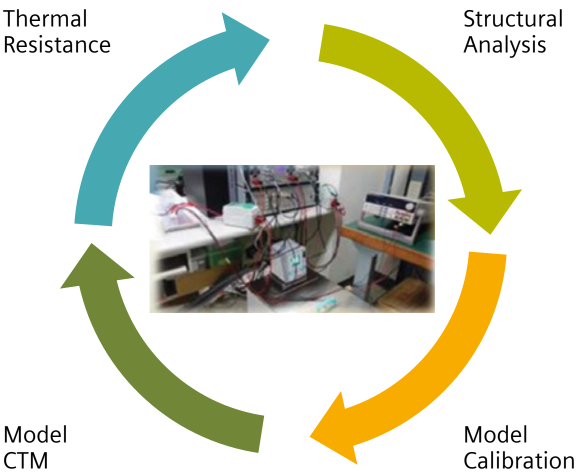


Figure 2: Novel workflow involving test and simulation

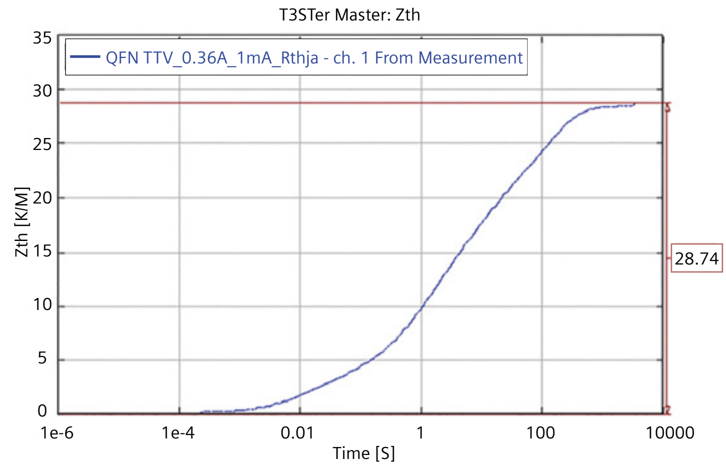


Figure 3: Z_{th} thermal impedance of a QFN package

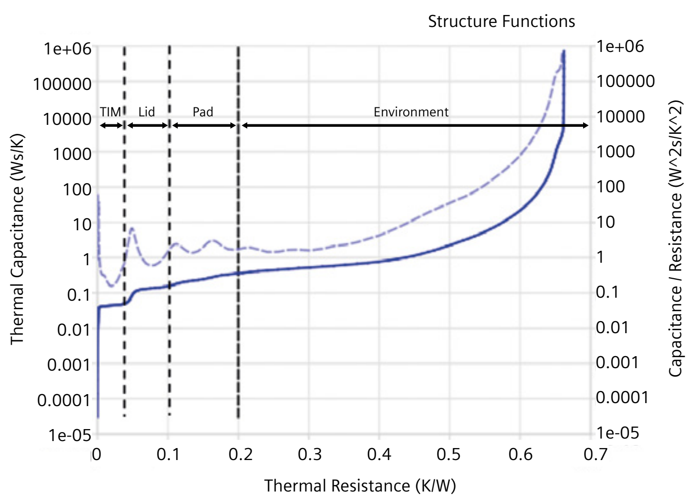


Figure 4a: Structure function curve for a HFCBGA package

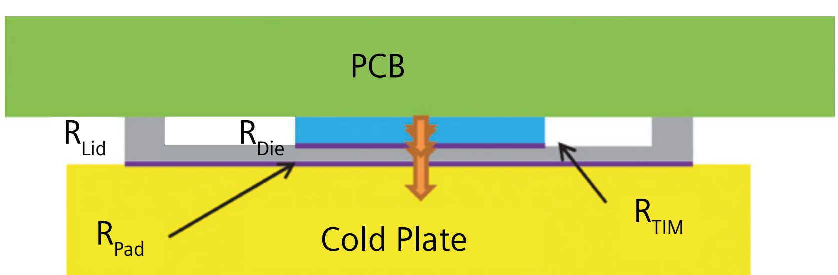


Figure 4b: Cross-sectional view of a HFCBGA Package

optimization studies on the IC package geometry prior to releasing the product. To that end, traditional test methodology is not able to help with this requirement. With the simple Still-Air, Ring Cold plate or Top Cold plate test harnesses, only a few point temperatures are obtained on the outside of the packages, but information about the actual structure cannot be extracted. Ideally, information on the internal structure needs to be known to optimize the design.

Novel workflow

A new workflow is now being used at ASE (Figure 2). This involves the use the Simcenter™ T3STER™ transient thermal tester hardware and the auto-calibration function in Simcenter Flotherm.

The IC Package is tested using the Simcenter T3STER initially. From the measured junction temperature, this yields the thermal impedance as a function of time for the package, as shown in Figure 3.

Information on the thermal resistances and thermal capacitances along the heat flow path for the measured package can be obtained by mathematically processing the thermal impedance curve, which results in a structure function curve. The structure function curve gives an insight into the internal structure of the package (Figure 4a and 4b).

Being able to quantify the resistances and capacitances of the individual internal structural elements of the packages is of added value to ASE's customers. They are able to identify thermal bottlenecks easily and ASE would be able to optimize the internal structures of the design, to reduce the junction temperature.

ASE use structure function graphs to calibrate the detailed Simcenter

Flotherm model of the IC package. Examples of a HFCBGA (Figure 5) and QFN package are shown in Figure 6.

Simcenter Flotherm's auto-calibration module is integrated into Command Center (used for What-If, Design of Experiments, and Design Optimization studies). By nominating the different design variables for optimization, the simulation model can be automatically adjusted to match the measured structure function. A calibrated Simcenter Flotherm model of the IC package gives confidence of its accurate steady state and transient behavior.

With a calibrated Simcenter Flotherm model it is quick and easy to carry out design studies to optimize and improve its thermal resistance and thermal behaviour. Using simulations to do this saves time, effort and cost compared to creating and testing physical prototypes.

Finally a dynamic compact thermal model (DCTM) can also be obtained from the Simcenter T3STER-Master analysis software after analyzing the measured junction temperatures. This DCTM model will be in the form of a R-C ladder network model, as shown in Figure 7.

The DCTM predicts temperatures at the important nodes in the model, e.g. Junction, Case, Board. Crucially, the geometry of the internal design and other proprietary information is kept confidential and the grid count for this DCTM is very low compared to a full 3D detailed model in Simcenter Flotherm. This has a huge benefit in terms of

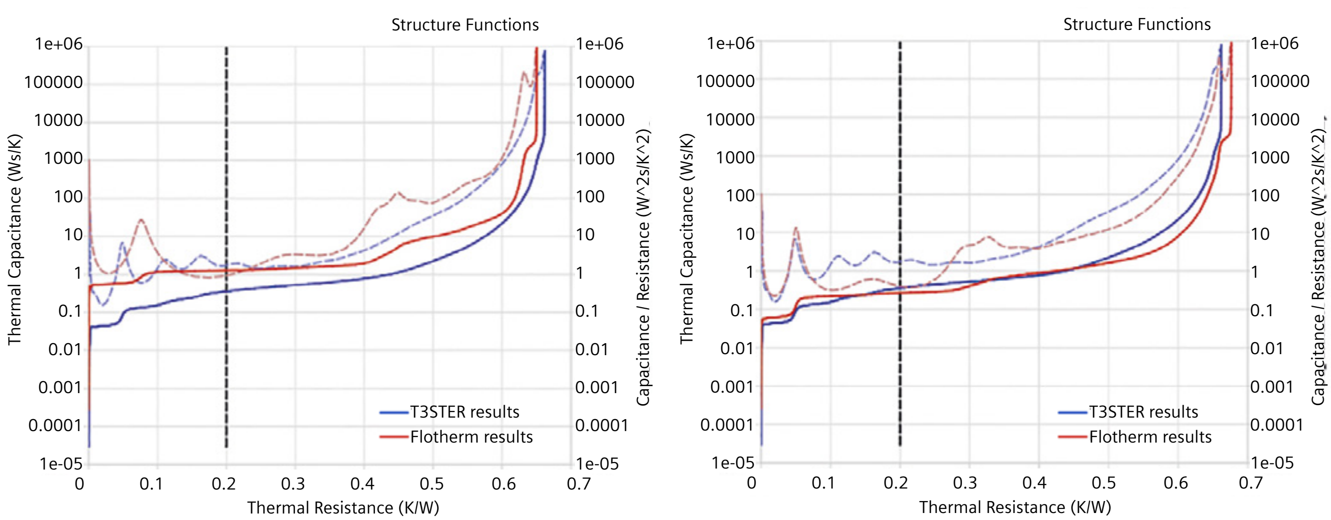


Figure 5: HFCBGA structure function curves before and after calibration

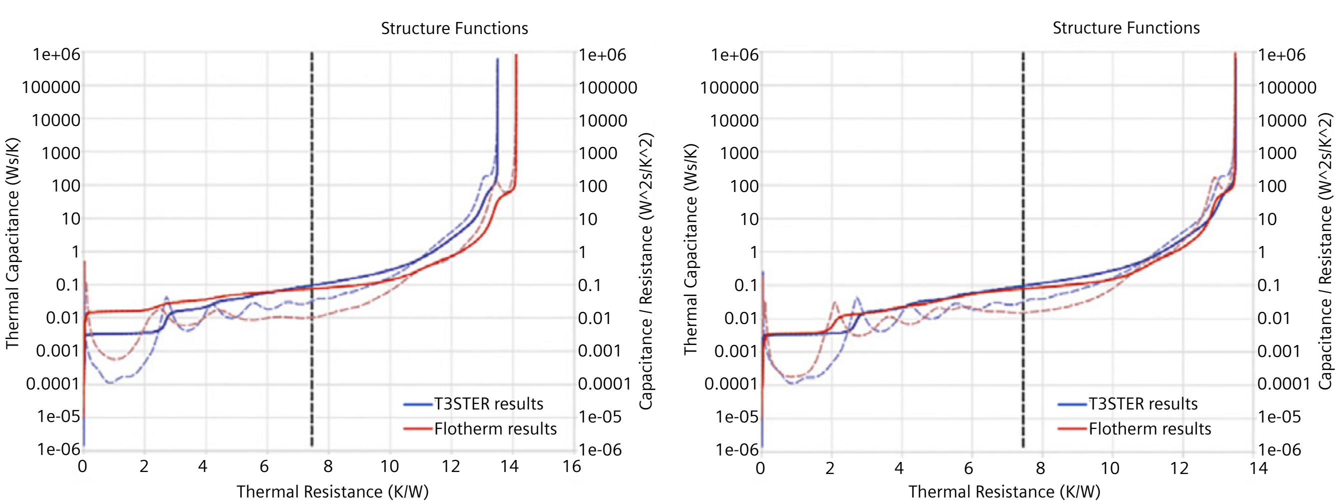


Figure 6: QFN structure function curves before and after calibration

accuracy, (shown later), and solution time.

Thermal resistance measurements
Using the example of a QFN and a HFCBGA package, when we compare the results differences from the transient test method used by Simcenter T3STER with that of traditional static test methods, we see one order of magnitude difference with the high-performance flip chip BGA (HFCBGA) package (20.6 percent) compared to the QFN (2.6 percent), as shown in Figure 8. The power dissipation for the QFN package (2.5 watts) was much lower than the HFCBGA package (100 watts). ASE surmise that with an increasing power dissipation, the differences in results between the static and dynamic test methods are magnified.

In the static test methodology, point temperatures are measured on the case surface. Consequently, the location of the thermocouple on the top surface will have an effect of the calculated resistance. On the other hand, the dynamic test method uses an electrical test (JEDEC Standard JESD51-1) to sense the junction temperature. The heat flow path taken by heat being dissipated from the active area of the die to the package case is also measured. The overall package surface is included in the measurements. The results from this method are also much more repeatable.

Performance of the calibrated Simcenter Flotherm models
The improvements in the temperature improvements are illustrated in Figure 9. In the bar chart, the calibrated IC models of the QFN and HFCBGA packages are less than one percent difference compared to the measured test results. In comparison, the non-calibrated models have larger errors of over two percent difference.

Accuracy of compact thermal models
We can also compare the accuracy of the exported dynamic compact thermal models (DCTMs) from the Simcenter T3STER measurements. A transient system level model of an Access Point Router was created (Figure 10), originally with calibrated detailed models of the QFN and HFCBGA packages on the PCB.

The detailed IC models were then replaced with the DCTMs. Plotting the junction temperature response curves

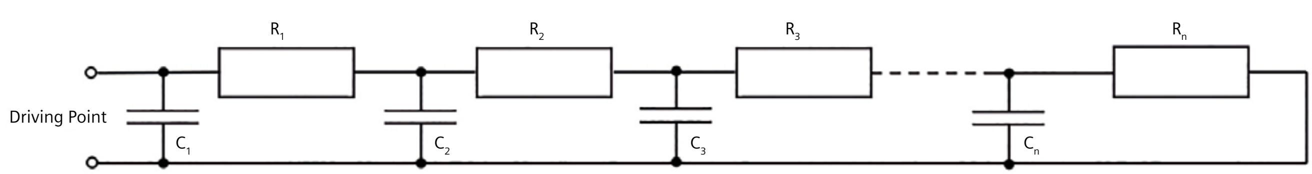


Figure 7: Dynamic Compact Thermal model in the form of a R-C Ladder Network

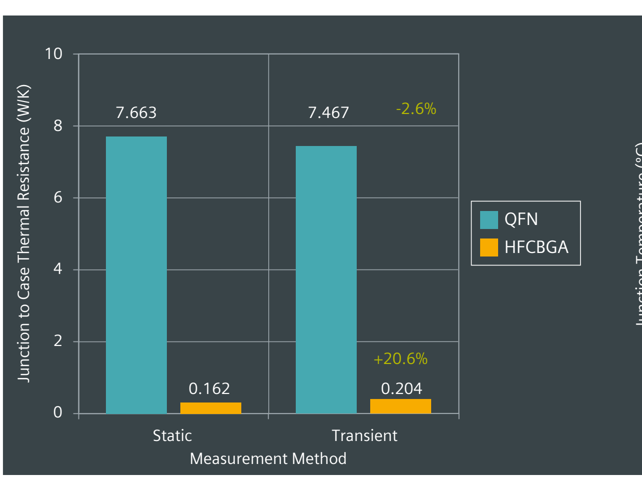


Figure 8: Differences in measured Junction to Case Thermal Resistances using Static and Transient measurement methods

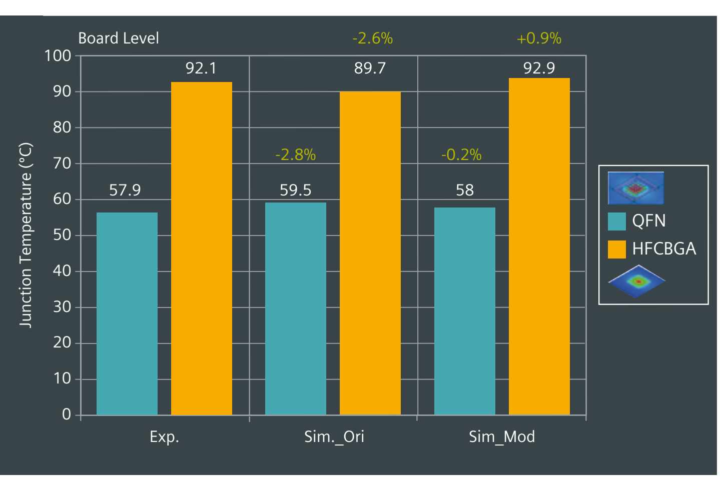


Figure 9: Improvements in Junction Temperature predictions with calibrated models

of the two packages, the percentage differences between the detailed and DCTMs are very good. The differences are below 10 percent, as shown in the comparison in Figure 11.

Conclusions

With the Simcenter T3STER thermal resistance measurements, ASE are able to quickly provide the important thermal metrics and accurate DCTMs of IC packages. Using the structure functions ASE are able to quantify the internal structure within the package. The calibrated detailed Simcenter Flotherm models can also be used to further optimize the geometry of IC packages. Consequently, this new workflow is able to provide added value to the design team and ASE's customers. ■

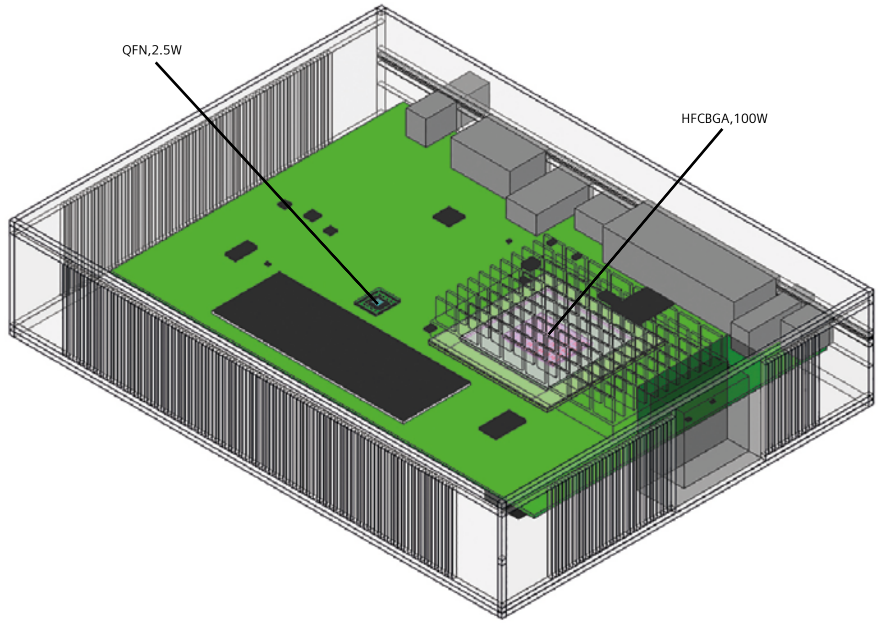


Figure 10: Simcenter Flotherm model of an Access Point Router

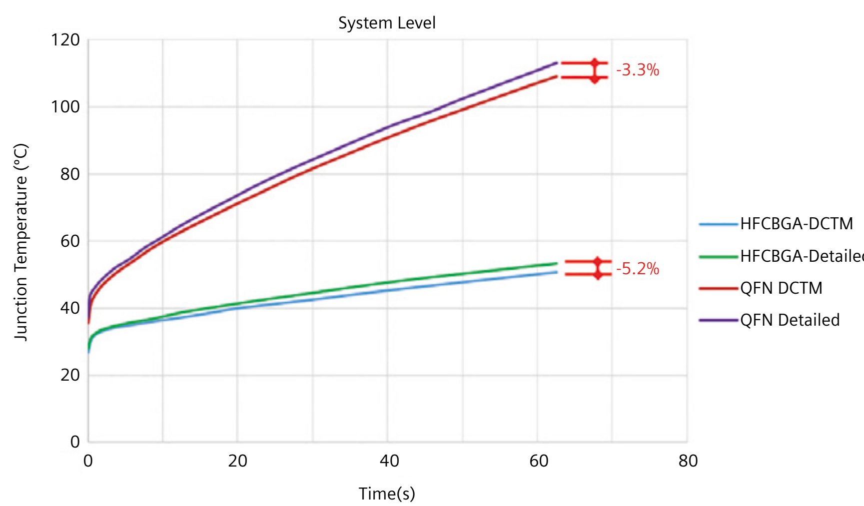


Figure 11: Transient response of detailed and dynamic compact thermal models of the QFN and HFCBGA packages in the AP Router

"With a calibrated Simcenter Flotherm model it is quick and easy to carry out design studies to optimize and improve its thermal resistance and thermal behaviour. "

Figure 1: Lap simulator using Simcenter Amesim

HORIBA MIRA

Automotive engineering consultancy uses Simcenter testing to assess the sound quality of electric vehicles

Measuring noise, vibration and harshness
Electric vehicles represent a huge step change in terms of measuring acoustic performance, also known as noise, vibration and harshness (NVH). This is a particular challenge for automotive engineers who have spent years assessing internal combustion (IC) engines. As Mark Randle, NVH Team Leader at HORIBA MIRA, explains: "There are specific difficulties around the assessment of noise, vibration and harshness in electric vehicles. Whereas an internal combustion engine generates obvious low-frequency noise, the motor within an electric vehicle creates higher-frequency noises which are often less pleasing to the human ear. At the same time, any noise coming from the road surface or from wind is more noticeable to the driver and passengers and affects their perception of auditory comfort."

Mark Burnett, technical lead for the noise and vibration attribute, expands on this point: "In a car with an IC engine, the harmonics increase in frequency as the vehicle accelerates. These harmonics provide useful feedback to the driver, but they become a nuisance if they are too loud. An electric vehicle will also emit harmonics, but they tend to be higher orders and are often perceived as less pleasant whines. This results in a compromise; we want to give the driver feedback, but we do not want these whines to be too prominent over the background road and wind noise. A balance has to be achieved."

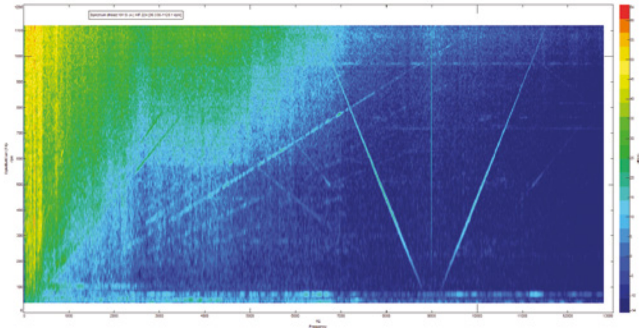


Figure 2: Noise only

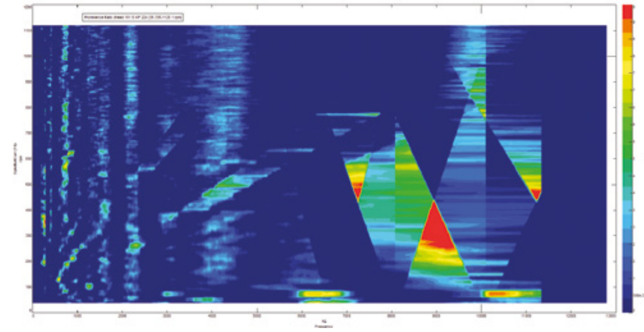


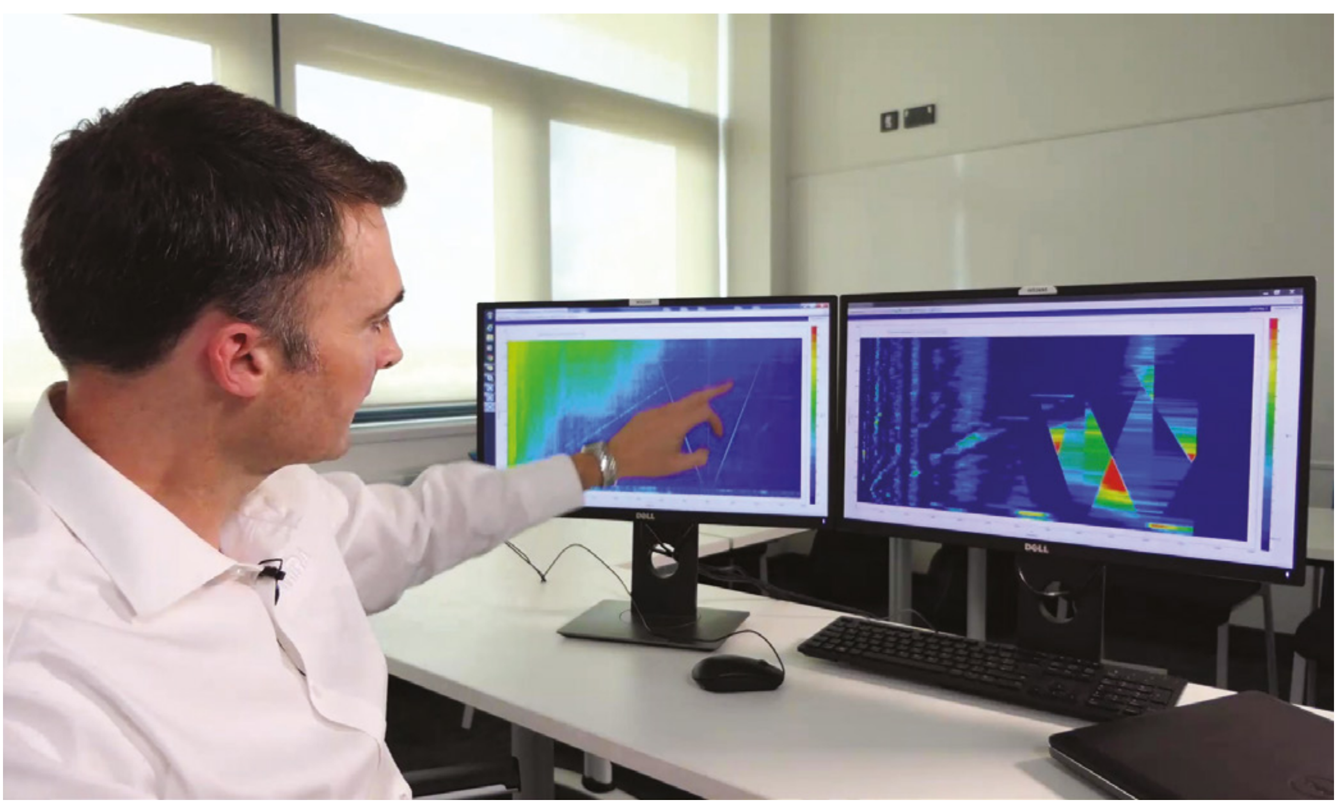
Figure 3: Prominence ratio only

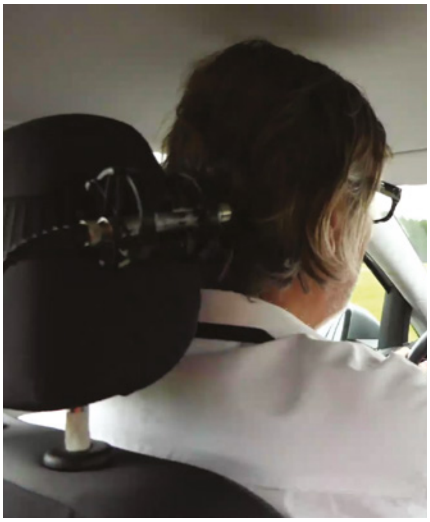
With an automotive reputation that goes back more than 70 years, HORIBA MIRA has the relevant experience and expertise to tackle such contemporary industry challenges. The company is well known for its proving ground, test facilities and engineering consultancy services. As Nick Fell, engineering and technology director, notes, "The great value we add is to understand and define the targets that our customers and end users require, then devise technical solutions that deliver those attribute requirements."

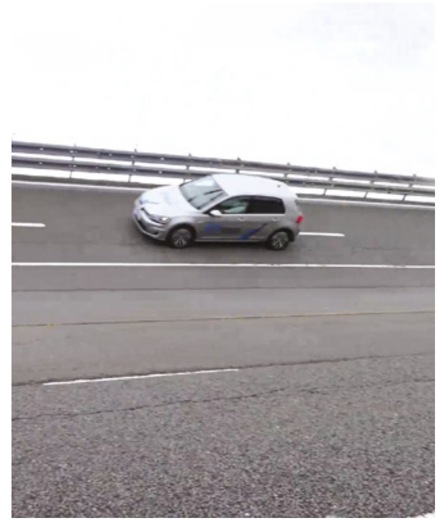
A member of the HORIBA Group, based in Japan, HORIBA MIRA has 650 full-time employees and revenues of £65 million per year. Its international customer base ranges from ambitious start-ups through component suppliers to globally established vehicle manufacturers.

Understanding sound and its origins

The NVH department at HORIBA MIRA undertakes extensive analysis of the level and quality of sound within different types of vehicles. Transfer path analysis (TPA) is one of the fundamental techniques used to measure interior noise and vibration and break these down into contributory paths. When microphones and vibration sensors are fitted to a car, it is possible to measure the frequency response of the structure at different speeds and identify their exact source. "Noise and vibration reach the driver either through the structure







"Our use of Simcenter SCADAS hardware for data acquisition means that we can efficiently measure the NVH behavior of vehicles."

Mark Burnett
NVH Technical Lead
HORIBA MIRA

or through the air," notes Randle. "It is important to understand the exact route because we can then make design recommendations to our customer if necessary."

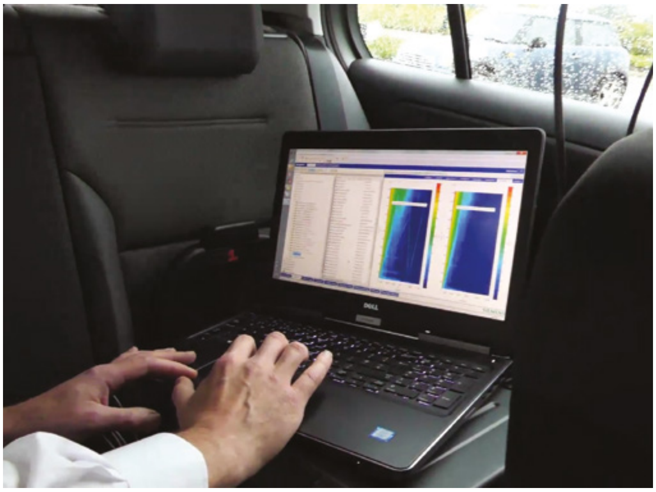
Specialist software and hardware is critical for this type of work and HORIBA MIRA has been using the Siemens Simcenter testing solutions for more than 25 years. Simcenter Testlab software and Simcenter SCADAS hardware are a complete solution that includes an extensive range of tools that can be used to identify loads and obtain transfer functions and operational data. "The Siemens solution is part of our offering," says Randle. "The capability it gives enables us to be more efficient, from design through simulation to validation. With our license model, we have access to a rich and wide range of methods, both for acquisition as well as processing of the data. This allows us to select the best methods for different needs. Thanks to this licensing model we have an extensive range of powerful software available to us."

Burnett uses Simcenter Testlab on a daily basis. "Through signature testing and analysis, we can acquire operational data from a vehicle and separate out the higher frequency orders that tend to be present in an electric vehicle, even in the presence of background noise," Burnett says. "The spectral test and modal analysis applications enable us to understand the various resonances within a structure and measure the required transfer functions with different excitation techniques. Using this data we can assess whether making a design change, such as stiffening a component, would reduce a vehicle's interior noise. Finally, the desktop reporting feature provides a straightforward and convenient method of visually presenting and interrogating data."

Expanding technical capability

In line with its ethos of continuously developing its capability, HORIBA MIRA undertakes independent research as well as customer-focused investigations. On a recent project the company purchased a commercially available electric car so that it could fit it out with instrumentation and conduct extensive analysis. "We set out to deepen our understanding of electric vehicles and validate the TPA process using the Siemens solution by working with a Volkswagen e-Golf," Randle explains. "This TPA exercise allowed us to quantify and rank the structure-borne noise contributions through the motor mounts, the driveshafts and the airborne noise radiated from the motor itself."

"At HORIBA MIRA, a lot of our work is focused on developing prototype vehicles and when we first take delivery of them it is quite straightforward to make improvements using relatively simple techniques," Burnett adds. "As the prototypes mature we need to use more detailed methods, such as TPA, to make further improvements. It was therefore very useful to focus on a car of such caliber; the project confirmed that we can achieve very strong correlation even with a quiet electric vehicle."



Ensuring efficiency and reliability
"The instrumentation and physical testing involved in TPA are time consuming," Randle notes. "However, the process delivers significant data and with Simcenter Testlab we have data acquisition combined with data processing on one platform. That means we obtain instant results when we are out testing on the track and can make immediate decisions to move the development process forward efficiently."

"It's one thing creating a software that is mathematically correct, that is a given," Burnett says. "It's far more difficult to design a piece of software that can be implemented effectively within a commercial environment and, with Simcenter Testlab, Siemens has done that very well."

"Electrification, alternative fuels and autonomy are increasing the complexity of vehicles," Fell observes. "It is impossible to physically test every use case and, although we expect physical testing to increase, we expect simulation to grow even more quickly. That is why the validation of simulation models is extremely important. Our use of Simcenter SCADAS hardware for data acquisition means that we can efficiently measure the NVH behavior of vehicles, cross-check with simulation results, make reliable recommendations to our customers and ensure that we maintain our leading role in the marketplace." ■

"With Simcenter Testlab we have data acquisition combined with data processing on one platform , that means we obtain instant results."

Mark Randle
NVH Team Leader
HORIBA MIRA

NATRAX: A comprehensive testing track

Asia's largest automotive proving ground uses Simcenter to offer state-of-the-art pass-by noise testing and engineering capabilities

National Automotive Test Tracks (NATRAX) is a world-class automotive proving ground for the comprehensive testing and evaluation of all vehicle types. It is set on 1,200 hectares outside of Indore, India. The facility is designed to cater to the testing needs of the Indian and Asian automotive industries. It offers many different track designs and surface coatings to test vehicles against varying conditions and terrains. The facility is used to evaluate the functional performance of vehicles with regards to speed, acceleration, breaking, fuel efficiency, noise, vibration, handling, stability, and more. With its vehicle dynamics laboratory, NATRAX is also a center of excellence for vehicle dynamics assessment and engineering.

NATRAX is one of the automotive test centers under the umbrella of the National Automotive Testing and R&D Infrastructures project (NATRiP). NATRiP is an initiative funded by the government of India to support the growing Indian automotive industry. NATRiP invested over $200 million (USD) to create this world-class facility.

Combating noise pollution to improve public health

One of NATRAX's primary objectives is to help reduce noise emissions by providing vehicle manufacturers with cutting-edge facilities and services for acoustic engineering. Noise pollution has damaging effects on public health, with consequences ranging from stress and ill-being to impairing cognitive performances, disturbing the human hormonal system, affecting the cardiovascular system and increasing the risk of stroke. Similar negative effects have been observed on the fauna in and near urban or noisy areas. Road traffic accounts for more than 80 percent of total noise pollution, and as world population rises, so does traffic. Consequently, decreasing noise emission in the transportation industry has become a priority to improve environmental safety with a positive effect on public health.

Dr. N. Karuppaiah is the additional director and site head of NATRAX. In this role, he is tasked with finding solutions for the challenges associated with road transportation, including the necessity for reduced noise emissions.

"Reducing the noise at its source is the most effective noise abatement approach," says Dr. Karuppaiah. "The complex and pervasive problem of noise pollution has no single solution. It requires a combination of short, medium and long-term approaches and careful consideration of the nature of the noise source."

State-of-the-art facilities

Pass-by noise testing designates a mandatory procedure which certifies that current and newly developed vehicles do not exceed the noise emission limits sets by local and international rules and regulations. Governments and regulatory institutions worldwide take various actions to safeguard public health and limit the impact of traffic growth and the resulting noise pollution. They set legislation and impose norms on vehicle noise emissions which lower acceptable noise level limits for both vehicle pass-by and tire rolling noise levels. These norms include pass-by and coast-by noise testing procedures as prescribed by the International Standards Organization (ISO). These tests are regulated mainly by the United Nations Economic Commission for Europe (UNECE), which promotes global harmonization of vehicle regulations. Apart from maximum noise levels for combustion engine vehicles, minimum noise levels are imposed for hybrid and electrical vehicles. These make a very limited amount of noise at low speeds and impose safety risks for bicycle riders and pedestrians, especially children and the visually impaired.

NATRAX's noise testing track is split into two surfaces. The first surface is

compliant to ISO 10844:2014 and the second surface to ISO 10844:1994. Both surfaces used to homologate vehicles according to the widely used ISO 362-1 pass-by noise testing standard and its regulatory counterpart UNECE Regulation 51.3. The second surface is designed to certify vehicles according to the standard's latest revision. Both test surfaces are standards compliant in terms of surface homogeneity, texture depth, residual void content and noise absorption coefficient. The entire track series has lighting arrangements to allow night testing when temperatures are within range of the standards and environmental background noise is typically at its lowest.

"Testing is an essential step in the process of developing new vehicles, from their components to their full systems," says Dr. Karuppaiah. "In India, the availability of appropriate testing facilities was limited and not aligned with the rising demand from the vehicle and component manufacturers. This was a bottleneck for the development of the local transportation industry. The new full-fledged proving ground now covers the testing needs of all types of vehicles, from two- and three-wheelers to passenger and commercial vehicles."

With regards to noise abatement, the testing facilities include world-class pass-by noise testing tracks, helping manufacturers comply with the latest standards and regulations.

The track is used for development and homologation testing according to the applicable standards for pass-by noise testing. It is also employed to perform vehicle interior noise, rolling noise or stationary noise measurements. The pass-by noise tests measure noise emitted as the vehicle passes by the microphones at a given speed, gear and acceleration ratio. Precise evolution of overall levels in function of vehicle position, speed and acceleration are calculated according to the standards. The next step in pass-by noise engineering is determining the source contribution to the pass-by noise levels.

This includes interior noise test measurements that can be performed simultaneously with pass-by noise tests, such as the noise at the driver's and passenger's ear level, and rolling noise measured at the tires while a vehicle is decelerating with the engine off and the gears disengaged. Finally, the stationary noise test is measured with microphones by the vehicle exhaust as the operator revs the engine to higher rotations per minute (rpm).

The NATRAX test tracks are designed to support the flawless execution of all these tests according to various national and international standards. They are equipped with leading-edge equipment to perform accurate measurements, including light barriers, weather station, microphones, and Siemens Digital Industries Software's Simcenter SCADAS data acquisition hardware and Simcenter Testlab analysis software.

"We have been recently equipped with a complete pass-by noise testing system from Siemens to perform accurate, quick, repeatable and reliable measurements."

Dr. N. Karuppaiah
Additional Director and Head
NATRAX

"Simcenter Testlab gives us a very detailed, user-friendly reporting structure," says Sagar Bendre, project engineer, NATRAX. "It builds the standard procedures which guides us through the testing processes but also offers additional information on the vehicle's aggregate noise performance beyond a simple 'pass' or 'fail.'"

Pass-by noise testing procedures
Accurate exterior pass-by noise measurements require reliable equipment and a systematic approach. Measuring by using sound level meters, for example, would yield results that may not account for vehicle and atmospheric parameters or monitor the test conditions.

"We have been recently equipped with a complete pass-by noise testing system from Siemens to perform accurate, quick, repeatable and reliable measurements," says Dr. Karuppaiah. "We are now able to monitor all parameters comprehensively as per the requirements. In the near future, we are considering placing permanent pass-by noise testing equipment on the test track. Where manufacturers need to perform more tests in a shorter timeframe, we will upgrade our track equipment to allow for continuous testing of vehicles."

Revised pass-by noise procedures make testing more challenging and create the need for better data management and more user guidance. More precise driver guidance, for instance, has become paramount. This contributes to maximizing the number of successful, valid pass-by noise test runs. The Simcenter Testlab Driver's Aid App gives clear, unmistakable instructions to the vehicle driver to make sure the acceleration starts at the right position and at the correct speed.

In the future, the Simcenter multi-vehicle pass-by noise solution will enable NATRAX engineers to perform more tests per day, with multiple vehicles being driven simultaneously. In this robust configuration, each vehicle is equipped with its own measuring system and a laptop. Simcenter SCADAS

pass-by noise software uses a global positioning system (GPS) sensor to measure vehicle speed. All data is recorded with GPS-based absolute time stamping for later synchronization. Multiple sets of microphones are connected to a track-based Simcenter SCADAS system. After each measurement, data from the vehicle and track systems are merged using GPS absolute time stamping and are directly processed into results and an overview report for the driver. Thanks to the multiple pairs of microphones, Simcenter Testlab software can automatically select the one at which the speed is closest to the target center speed. This helps obtain repeatable results and greatly increases the success rate of a test.

Beyond homologation

Fast and accurate homologation results are not the only outcome of vehicle acoustics tests at NATRAX. While powertrain noise remains the main contributor to the overall exterior noise level of internal combustion engine vehicles, noise abatement efforts increasingly focus on reducing tire noise.

New requirements have been set by the Indian government concerning tire rolling noise levels, tire wet grip and rolling resistance. NATRAX's facilities shall offer both the vehicle and tire industries a one-stop solution for all of their noise, vibration, and harshness (NVH) benchmarking and testing needs. NATRAX's pass-by noise testing facilities support this with the UNECE Regulation 117 tire noise testing standard.

"NATRAX's ambition goes beyond offering state-of-the-art reliable service and facilities for vehicle and part homologation," says Dr. Karuppaiah. "The analysis capabilities of Simcenter Testlab software brings deeper engineering insights into the NVH behaviour of vehicles. Advanced transfer path analysis techniques such as acoustic source quantification allow engineers to identify, quantify and rank the contributions of separate subsystems, such as intake, powertrain, exhaust, tailpipe and tires, to the overall pass-by noise level. Those techniques are efficient troubleshooting tools for noise reduction; they are also employed for precise target setting early in the design process.

"With our facility, equipment and expertise, we are confident that we offer the industry the toolset it needs to make the world a quieter place." ■

"The analysis capabilities of Simcenter Testlab software brings deeper engineering insights into the NVH behavior of vehicles."

Sagar Bendre
Project Engineer
NATRAX

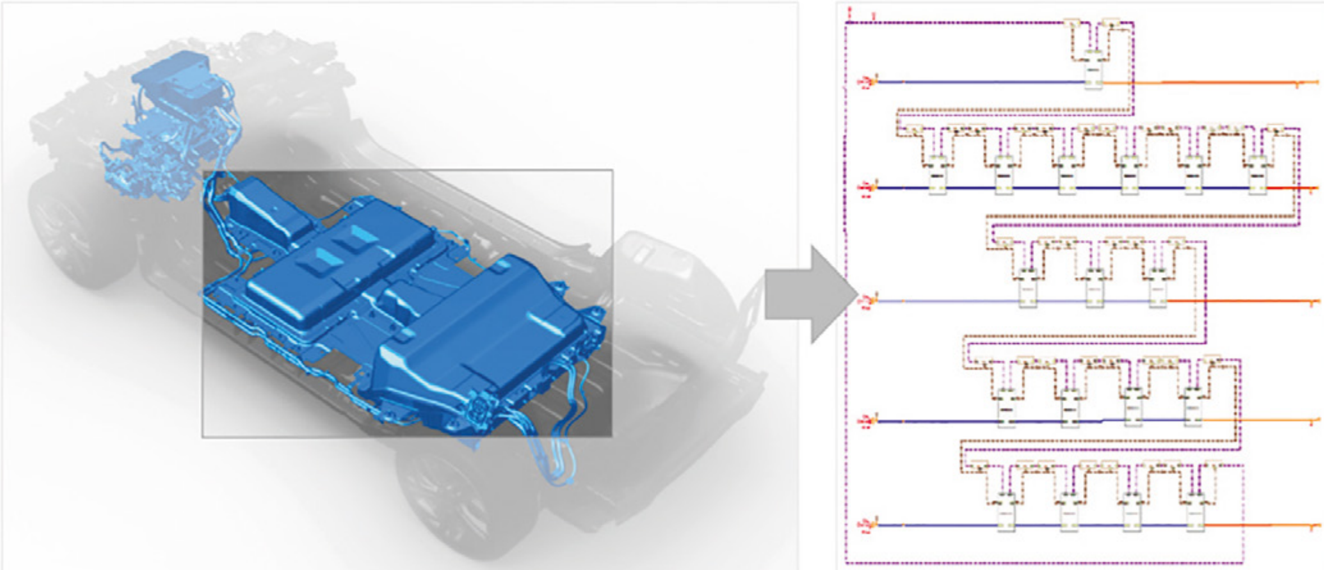
Mission Possible: Optimize a battery pack while reducing costs

Siemens solutions enable PSA Peugeot Citroen to reduce product development time from months to weeks

Navigating the road to electrification
2020 is a key year for the automotive industry. New regulations and carbon dioxide (CO_2) emission standards for cars mean there is no way around electrification. All external factors are converging, including government incentives, tighter regulations and falling battery prices. Boston Consulting Group's (BCG) latest global automotive powertrain forecast shows sales of electrified vehicles (xEVs) growing even faster than expected. According to BCG, these cars will command one- third of the market by 2025 and 51 percent by 2030, surpassing sales of vehicles powered purely by internal combustion engines (ICEs).

All original equipment manufacturers (OEMs) are speeding up plans to electrify cars, and the PSA Groupe is no exception. The group has been committed to clean and sustainable mobility for quite a while so the choices they made in the past make it ready to play its part in the energy transition. PSA Peugeot Citroen's objectives is to have its vehicle range completely electrified by 2025.

The battery is at the heart of electrification
The battery is a key component for enabling electrified vehicles to meet customer expectations. Range anxiety remains an important barrier to address. Most electrical vehicles batteries have an eight-year warranty or a 160,000-kilometer (km) (100,000-mile) drive limit. Therefore, OEMs have to develop strategies to slow down battery aging. One of the most impactful criteria for the battery aging is the temperature variation that it endures. Although there is larger battery capacity at high temperatures, it drastically shortens battery life. Thermal management of batteries is critical for achieving optimal temperatures for any driving condition. This enables the user to determine the perfect balance between capacity and battery life.



Detailed Model

Simplified model (391 explicit variables)

Figure 1: eCMP comparison between Simcenter Amesim and 3D model

In this context, it is crucial for the battery cooling system to be designed in a way that balances other vehicle performance attributes and optimizes battery capacity versus life. It cannot be oversized as it would impact overall vehicle performance because it would be too heavy, require additional money to build a more complex system and degrade vehicle aerodynamics. In addition, it cannot be undersized because it would risk compromising the safety of the vehicle, driver and passengers. On top of this, it is critical to design cars that strike the optimal balance between conflicting attributes like comfort, driving pleasure, performance and durability.

To cope with these challenging design requirements, OEMs need to adapt to new development priorities and build an engineering organization mapped around those key areas. PSA Peugeot Citroen had to make a strategic move in that direction. Angelo Greco, who is team leader of the battery system modeling and functional design department, focuses on functional design analysis and multi-physics modeling. Battery design and integration is at the crossroads of innovation and needs to fulfil challenging demands, not only for marketing requirements, but also for passenger safety and comfort to define the right components for the vehicle.

Defining the right battery for specific objectives

"The main challenge is that we can't make proper battery design analysis and evaluation without integrating it in the complete vehicle architecture," says Greco. "It is very complex because you have to take into account its multi-physics nature, including electrical, thermal, cooling and control parts in the same model. It is not an easy task and that's why we chose Simcenter Amesim to work on that engineering challenge."

Engineering the optimal battery thermal management system design and architecture while balancing costs, range, thermal comfort and durability is a critical task. Decisions must be made considering not only thermal safety and its impact on durability, but also on range and performance, cabin comfort and battery temperature. Multi-level modeling and multi-physics simulations have become pivotal for evaluating the impact of the architecture design on key performance attributes and anticipating control strategies validation.

"On top of those engineering constraints, we have strict development time requirements to maintain a competitive time-to-market," says Greco. "We have to be very agile. Sometimes we have to change a component or a model within a week or a day and adapt to new requirements or data from the supplier.

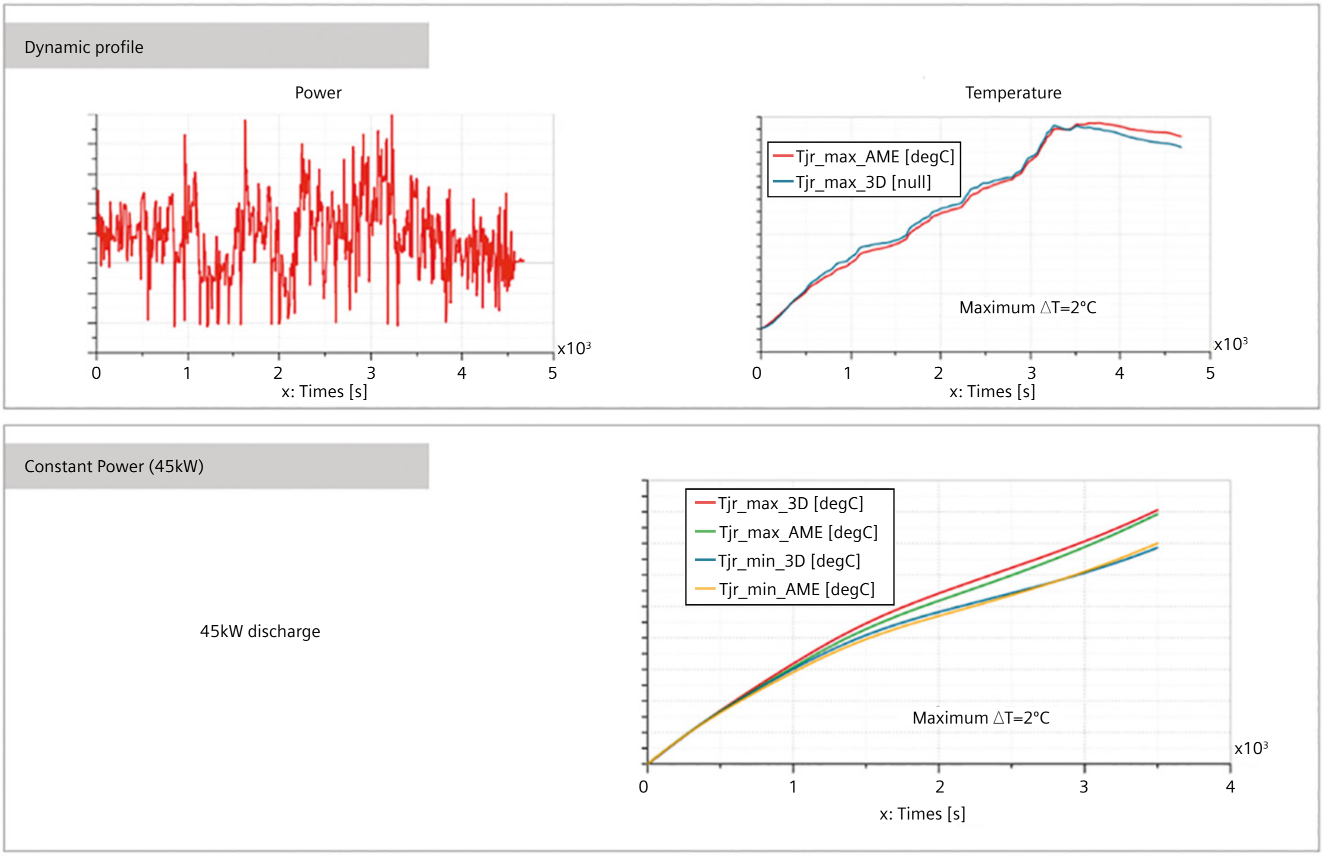


Figure 2: eCMP comparison between Simcenter Amesim and 3D model

The versatility of the multi-physics models is key to be able to realistically assess the impact of changes on the expected performance levels. That is one of the reasons we decided to use Simcenter Amesim for our multi-physics analysis as it helps us remain agile."

Developing battery system model from 3D design

To analyze battery thermal management, Greco has to understand how the battery is designed by PSA Peugeot Citroen suppliers. Tier suppliers usually size and develop the battery module by considering the worst use-case conditions to ensure the electric vehicle works under any conditions and the battery life range aligns with the eight-year warranty and meets regulation requirements.

Nevertheless, the battery is often oversized and so is the cooling system. Consequently, it costs more development time but also reduces the overall vehicle performance. According to Greco, "Oversizing the battery pack is a safe bet, but it leads to increased costs. And this can definitely be optimized. Having access to simulation enables PSA Peugeot Citroen to rapidly analyze battery performance and its thermal management. Further, it enables the firm to investigate alternative battery designs, validate them virtually and to make sure they meet the required levels of performance without compromising safety. We can also transmit required improvements to battery suppliers."

"We used to assess battery thermal management using 3D battery modeling for both static evaluation and cell thermal flow modeling," says Greco. "This happened too late in the development cycle and didn't allow you to anticipate any change in the battery design. So, it has been fundamental to find a way to transcribe 3D thermal and hydraulic model into 1D model with the addition of the electrical part in order to evaluate the battery thermal management in a reliable way early in the development cycle."

To succeed, Greco developed a methodology to develop a 1D model of the battery from a 3D thermal model using a nodes network. He reached similar results to the 3D thermal-hydraulic modeling but in shorter runtimes. "We used Simcenter Amesim to develop this approach that helped us not only save simulation runtimes, but also assess the dynamic thermal management of the battery versus a static assessment that we usually achieved using 3D thermal model for the battery coupled to a 3D CFD (cooling plate) model."

Challenging the supplier to obtain better cell design
Greco mainly worked on battery design for mild hybrid and electrical vehicles. "By using the models built with Simcenter Amesim we have been able to optimize the battery cooling system and architecture. Indeed, from the battery model provided by the supplier using the 3D to 1D simulation approach, I have been able to show the battery could have an overall thermal resistance of 0.9K/W (worst case) instead of the 1.8K/W proposed by the supplier. The new design (0.9K/W) was able to reject twice as much heat compared to the supplier proposal, for the same cooling conditions, providing the expected performance required in the technical specification."

Greco established that methodology early in the development cycle of a new electrical vehicle that enabled him to also opt for an "intrusive" design. Therefore, Greco explains that "the multi-physics simulation and results help us to predict performance but also to challenge the battery supplier to make them design a battery pack as efficient as the one they propose but requiring a more optimal thermal management system."

Saving time thanks to improved simulation engineering methodology
"Having developed that nodes network methodology to model the battery thermal management has been a great move forward to propose very detailed and specific battery design requirements and challenge the supplier," explains Greco.

This improved methodology enables the team in charge of battery modeling to make decisions earlier in the development cycle and define a battery architecture that enables them to reach reliability and safety criteria for an optimal overall vehicle performance. "With Simcenter Amesim, in some projects we reduced product development time from months to weeks using multi-physics modeling. This advanced methodology will enable us to improve our development process for future vehicle program development." ■

Interview

Taking the guesswork out of high-tech charger design

Simcenter 3D Electromagnetics helps Salcomp shorten the development cycle by 20%

Smart phone charger market leader Salcomp reduces a six month development cycle to five months by implementing the new Simcenter 3D Electromagnetic solution in its design process to deliver performance within physical size restrictions

The simple smart phone charger: they can be found everywhere, in our cars, in our offices, in our kitchens... A reliable, working charger is required for all kinds of devices: smart phones, tablets, headphones, ear buds...these might take the form of smart charging station, or more likely a jumble or wires and last generation chargers. It is safe to assume that there are a significant number of chargers out there, but who designs and makes all these chargers?

Industry insiders know Salcomp as the global leader in smart phone and tablet chargers. Originally founded in Salo, Finland in 1973, Salcomp has produced approximately 4 billion phone chargers over the past three decades, making the company a true pioneer in its field. Today, the company has a 520 million-piece annual production capacity and approximately 16,000 employees worldwide. Many of these developments at Salcomp have happened under the guidance of Lauri Puranen, an engineer working on charger design who has been with the company since 2010. Lauri is based in Shenzhen, China (Salcomp relocated from Finland, following their acquisition by Lingyi iTech) and is responsible for planar transformer technology development.

The former R&D director of Salcomp believed that planar magnetics would become more popular with the increasing demand for high-power density, so Lauri moved into electromagnetics.

"He encouraged me to study this technology, which today plays a huge role in power supply and planar magnetics transformation techniques," explains Puranen. "I did a lot of R&D work in the area of overall planar magnetics in Finland. Around 2017, adapting it to mass production started to look feasible and we had customer requests for simulation work on this level. Today, from the Shenzhen office in China, we work on quite a few high-power planar transformer designs using Simcenter 3D Electromagnetics."

Planar magnetics are a popular solution for applications where available space for magnetic components on printed circuit boards or PCBs have constraints. Compared to traditional wire-wound components, planar components are flatter, making this is a massively interesting technology for engineers like Lauri Puranen who need to be on the cutting edge of charger technology.

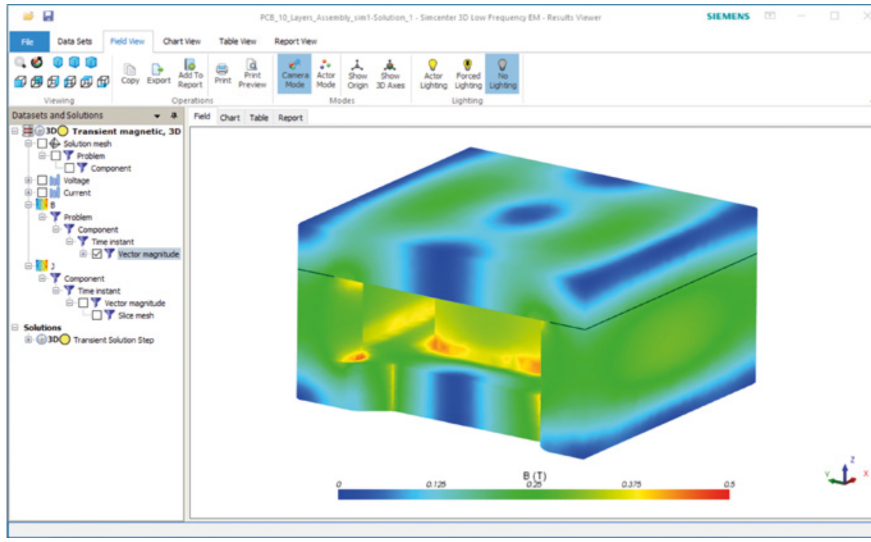


Figure 1: The flux density distribution in the core at peak current. The maximum value is less than 0.5 tesla (T), which satisfies the design requirements.

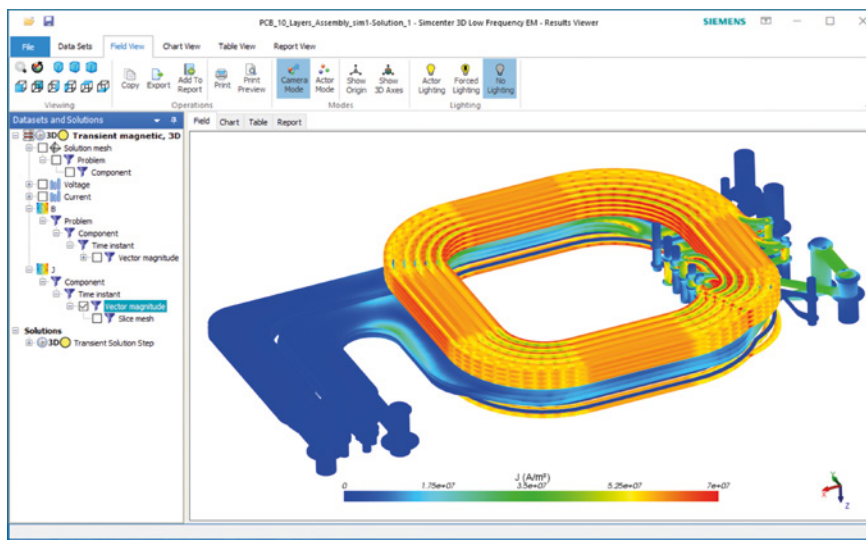


Figure 2: Current density distribution in the primary and secondary coil. The value in the secondary coil is a little bit low, which indicates that material utilization can be optimized further.

Looking for the GaN effect in electromagnetics

"If you look at the specifics of charger design, there have been quite significant efficiency gains on the semiconductor side. For example, semiconductor materials like Gallium Nitride (GaN) have made a huge difference in the performance of high-power transistors operating at high frequencies," add Puranen. "While the magnetics side of things has remained the same, so the major percentage loss in energy efficiency starts to be solely in the transformer."

Electromagnetics & Smart Phone Chargers

Lauri Puranen explains that he uses Simcenter 3D Electromagnetics since planar transformer design and dealing with electromagnetic interference or EMI issues are central to smart phone charger design.

"Traditional transformer design is pretty straightforward. For traditional transformers, it's more convenient to just make samples by yourself using your basic parameter calculation and measure the results yourself. In a best-case scenario, you have a self-made prototype in your hands on the same day you make your basic calculation," explains Puranen. "For planar transformers, however, you first need to prepare the files in your CAD software. This takes about 1-3 days. Then you send it to the PCB manufacturer and wait. Depending on the lead time, you might have to wait 2-3 weeks before you have the first prototype in your hands."

Like traditional transformers, the parasitic calculations required for planar transformers are also quite challenging.

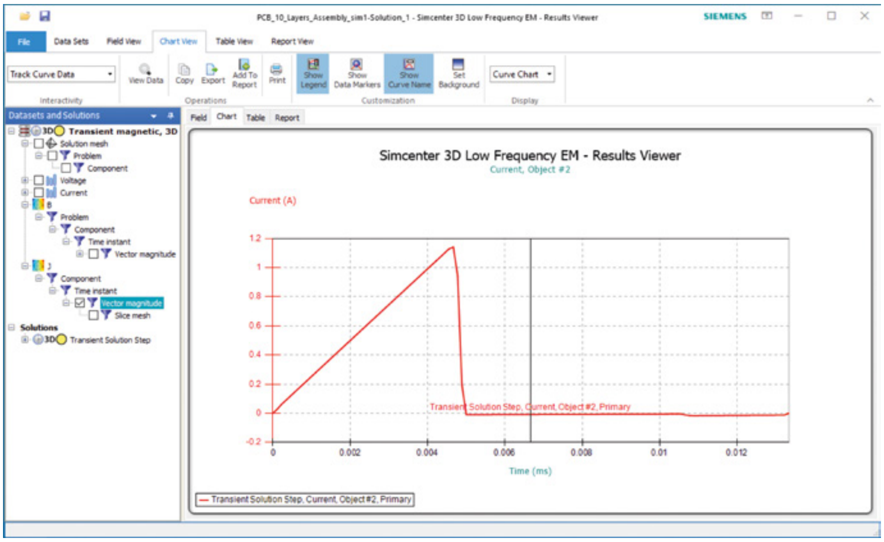


Figure 3: The current waveform in the primary coil. The peak current when switching off is around 1.2 amps (A) as desired.

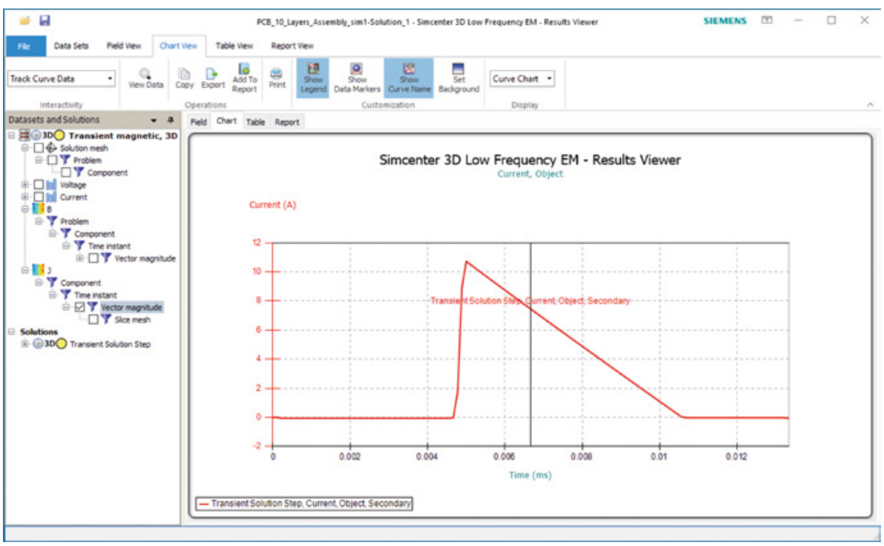


Figure 4: The current waveform in the secondary coil. The peak current when switching off is around 10 amps (A) as desired.

Most of the time, they don't match the real result. This is where accurate and advanced simulation is so useful.

"With accurate simulation results, like those we got from Simcenter 3D Electromagnetics, you can reduce the number of design of experiments (DOE) required to get to the planar transformer parameters that you need," adds Puranen.

Enter the engineering trickster: EMI

With magnetic components and capacitors that reduce size while increasing power density, planar transformer technology offers all types of benefits from cost and size savings to energy efficiency increases. This gives the team a lot of flexibility to adapt and create designs for a wide range of charger applications within the OEMs design parameters. However, any engineer who has worked with electromagnetics knows the challenge: EMI.

"Our main challenge is EMI and a rule of thumb with EMI is...there is no rule of thumb," explains Puranen. "What worked in one project might be terrible solution in the next one. Each project is different and this EMI challenge in planar transformers plays a key role in our design process."

Typically a solution for EMI issues would be to add filtering components to meet customer specifications. Although a workable solution, filter components cost additional money, and consider how many millions of chargers are manufactured. Too much extra material, like EMI filters, and the product is no longer competitive.

So the best idea according to Puranen is to optimize your original design to the max. "Poor transformer designs need lots of filtering components to meet customer specifications. Basically, these filters cost money and eat up the profit margin."

Enter Simcenter 3D Electromagnetics

This is where Simcenter 3D Electromagnetics steps into the picture. One of the newest modules in the Simcenter portfolio, Simcenter 3D Electromagnetics offers an advanced electromagnetics simulation solution for both low frequency and high frequency issues. More importantly, when it comes to material savings, Simcenter 3D Electromagnetics is an excellent tool to help determine where material is being overused or where it is not needed and can be removed to save costs and reduce weight. Users can specify a minimum efficiency percentage for the operating range of transformer being designed as well.

"We started using the new version after the Chinese New Year in January 2020. Our goal right now with Simcenter 3D Electromagnetics is simulate the optimal transformer so that we can have as few actual prototype rounds as possible," says Puranen.

This means that the team is trying to find the right mix between different electrical, magnetic and chemical engineering elements: finding the lowest total loss and finding the right balance between conduction loss in copper and core loss; finding the optimal balance between AC and DC loss and comparing different core material performances as well as finding the optimal level for common mode noise – without forgetting about other potential holistic EMI issues.

"It is hard to put a number on this as some of the work has been general research. For a specific project let's say we could save one prototype round. This is easily one month and shortens a typical total development time for us from 6 months to 5 months. This is good for our supply chain as well."

Still early days

Lauri Puranen was quick to point out that even though he is one of the first hands-on users of Simcenter 3D Electromagnetics, he is not an expert.

"The electromagnetics field as a whole is lagging behind in development. There is still vast areas for improvement, including fields that don't always match up like chemistry and electronics," says Puranen. "It took me a while to get up to speed. I am still really in the learning curve. Thanks to the help of Kang Chang, a Siemens electromagnetics expert, we've been able to explore what the real possibilities are for electromagnetics engineering at Salcomp. I also wanted to point out that the team at IDEAL GRP in Finland was key to our success. They introduced us to the new Simcenter 3D Electromagnetics software and their comprehensive training really helped get this project up and running fast. I am convinced Simcenter 3D Electromagnetics has a huge potential to really change the way we think about electromagnetic engineering."

Going into the summer of 2020, Lauri Puranen and his team are back at work in China, making the high-tech chargers and wireless charging pads for the next generation of smart phones and tablets. ■

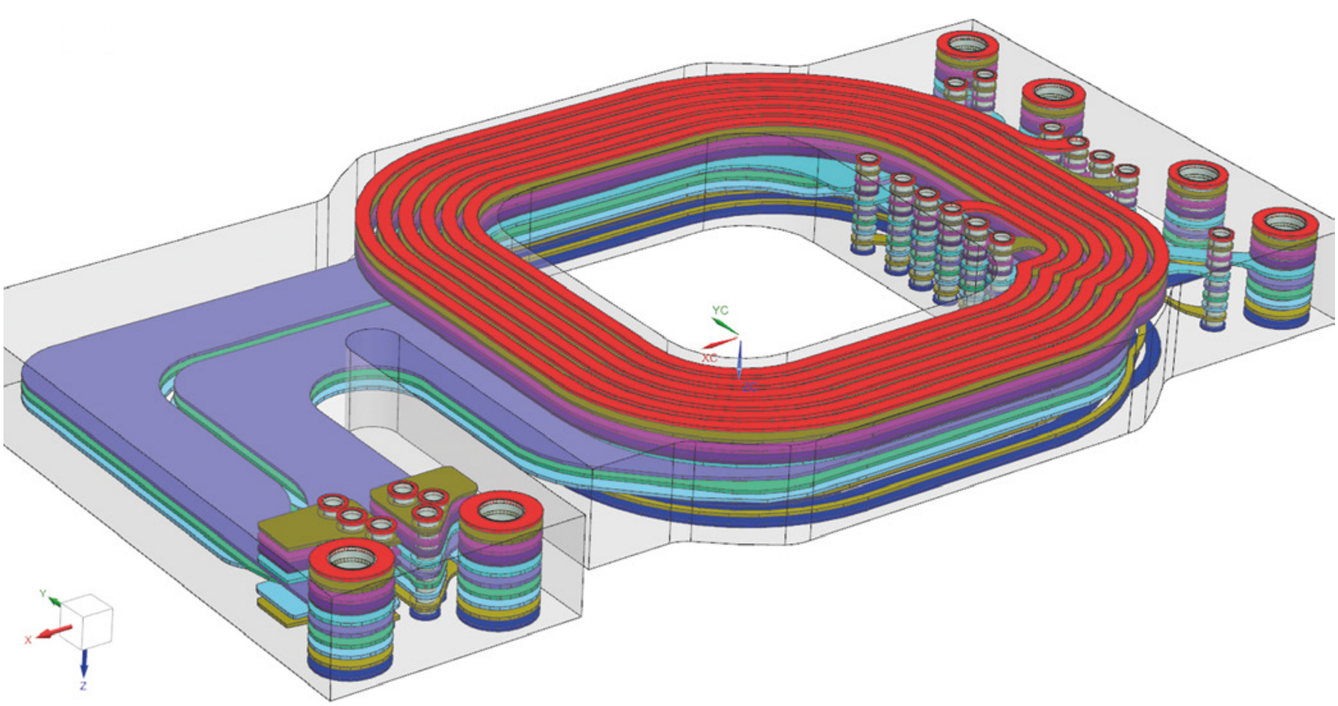


Figure 1: Large scale modal test

Modal testing made easy with the new MLMM technique

Modal testing is a very useful technique for verifying and understanding the dynamic behavior of complex structures. Its principle is to characterize a structure by its resonant modes with associated resonant frequencies, damping and mode shapes, which help identify potential issues or weaknesses in the design.

This technique has been widely used for decades on various types of structures; from small components to fully integrated aircraft as part of GVT (Ground Vibration Testing) campaigns, supporting the aircraft certification process. Next to this, the modal survey technique, commonly used in the space industry, helps verify the structural dynamics performance of spacecraft and space launchers.

However, efficiently conducting a modal test can be a difficult task. When processing measurement data to extract modal parameters, several choices must be made by the engineer, making it difficult to get reliable and consistent data. For instance, in the case of highly damped structures or large structures instrumented with hundreds of sensors with high modal density, properly choosing the poles of the modal model is challenging — it is not always straightforward and might require deep expertise. The introduction of the Polymax algorithm by Siemens has already led to significant improvement, providing more clarity in the stabilization diagrams. But verifying that the modal model fits well with the measured data is still a tedious task that might require many successive iterations.

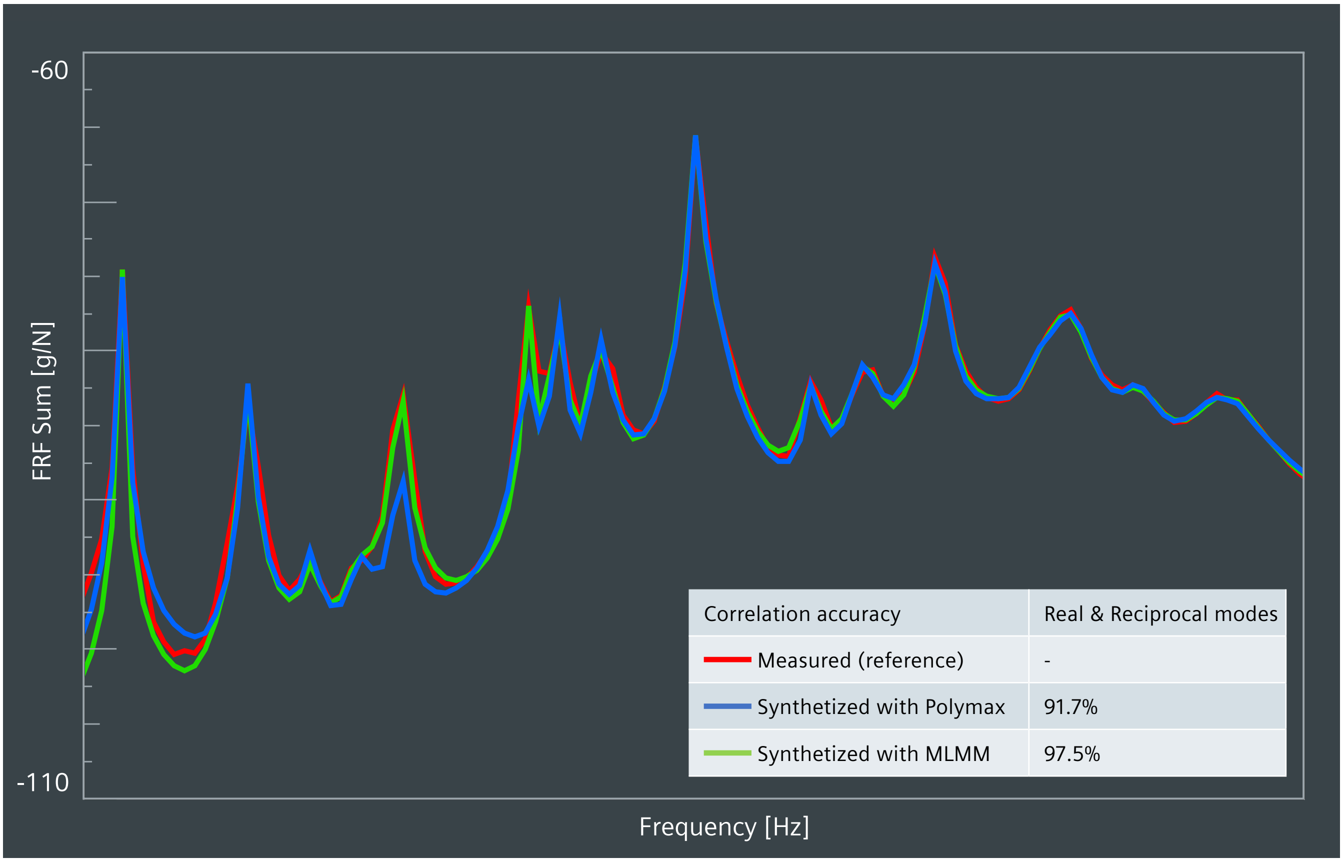


Figure 2: Improvement of FRF curve fitting with the MLMM modal technique

With the introduction of the MLMM (Maximum Likelihood Modal Model) algorithm into the Simcenter Testing Solutions portfolio, Siemens is making modal testing easier and more accessible to non-expert users, built on top of the current modal testing process. Starting from a set of measured vibration data, the MLMM algorithm automatically iterates on the parameters of the modal model to improve its accuracy and the fit to the experimental data for all measurement positions and for the frequency range of interest. This allows the user to get rid of the lengthy and tedious manual iterations.

Not only that, MLMM brings extra accuracy in terms of resonant frequency and damping estimates and accelerates processing tasks when dealing with a higher level of complexity of measured structures, allowing non-expert users to deliver more consistent data. The improvement of the modal model accuracy with the MLMM algorithm is especially remarkable when constraints, such as reciprocity or non-complexity, are imposed on the modes in view of finite element model correlation.

A typical scenario is when many sensors and exciters are used at the same time during a vibration test, which can cause issues in the modal estimation process. By using the MLMM optimization, this is automatically solved, and the local dynamic behavior is better represented. In the example shown in figure 2, where modes are extracted during a GVT on a complete aircraft, the correlation between measured FRFs (frequency response functions) and FRFs synthesized with the modal parameters significantly increases, especially in the case of real and reciprocal modes.

Thanks to MLMM, a more consistent model is obtained, which can then be used with higher confidence during the aircraft verification process, while keeping the existing testing processes unchanged. Regardless of whether the test involves simple or complex modal scenarios, MLMM is a useful technique to improve the way modal testing is performed and help test engineers achieve better results faster. With the new MLMM technique, modal testing has never been so easy. ■

Rising to the Challenge:

Designing the Next Generation of Traction Motors

The transportation industry is being transformed rapidly, driven primarily by the electrification of vehicles. One of the main challenges accompanying electrification is designing the next generation of traction motors for hybrid and electric vehicles (xEVs). The greatest concern is that currently available traction motors do not meet the performance characteristics required by future xEVs. We can summarize some of the main design challenges as:

- Developing high power density traction motors
- Eliminating or reducing the dependence on rare earth permanent magnet based motors
- Increasing efficiency (~95 percent or higher)
- Increasing the maximum speed range by several factors compared to current limits
- Controlling or mitigating the Noise, Vibration and Harshness (NVH) levels
- Ensuring their robustness against manufacturing tolerances, system faults and environmental changes

Design and simulation tools will be one of the key enablers for overcoming these challenges. To introduce their role on the above mentioned challenges, we consider a typical motor design V-cycle. At each step of this process the modern designer needs an extensive set of simulation capabilities.

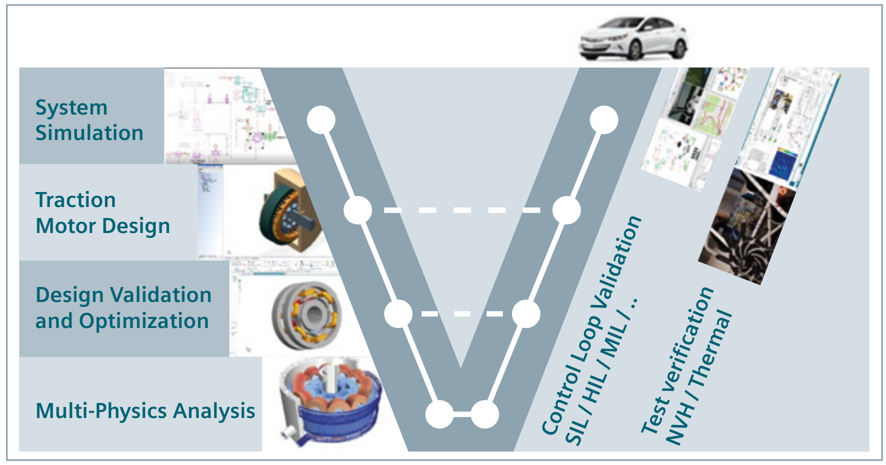


Figure 1: A typical traction motor design process V-cycle

System level simulations and sizing

In any traction motor design process, the first step is to obtain the performance requirements. This usually depends on the powertrain configuration (parallel, series, hybrid, etc.), transmission system (single, multiple speed), cooling system (liquid cooled, spray cooling, etc.), machine drive system (single-multi level inverters and converters) and the vehicle type (pure electric or hybrid). Typically, engineers carry out 1D system level simulations to obtain the torque-speed envelop of the required machine. This step may also include exploring what-if type scenarios as well, i.e., to consider the impact of changing the powertrain component sizes and configurations on the torque-speed envelop of the traction motor.

Motors are typically represented by their speed-torque-efficiency maps or lumped parameters (resistance, inductance, back emf, etc.) in 1D models. These maps and/or their lumped parameters are used to calculate the well-to-wheel vehicle efficiency, the energy efficiency, the acceleration, the vehicle range, the gradeability and other system level performance parameters. Ideally, motor representations are available at various fidelity levels that are temperature dependent. They are obtained from the motor design tools shown on the V-cycle.

The system level simulator should also be able to share model data and results with the drive and the cooling system design tools. Essentially, the idea is to ensure that system level impacts of any design change may be assessed at all stages of the design process seamlessly.

Motor design initialization and iterations

Once the performance requirements have been set, the design process begins in earnest. The main objective of this step is to obtain a single or a few design candidates that satisfy the performance criteria obtained from system level simulations. During this stage the engineers would usually use a template-based software containing a large number of built-in motor topologies. This enables

Figure 2: System level analysis of the NISSAN LEAF vehicle including its IPM motor using Simcenter Amesim

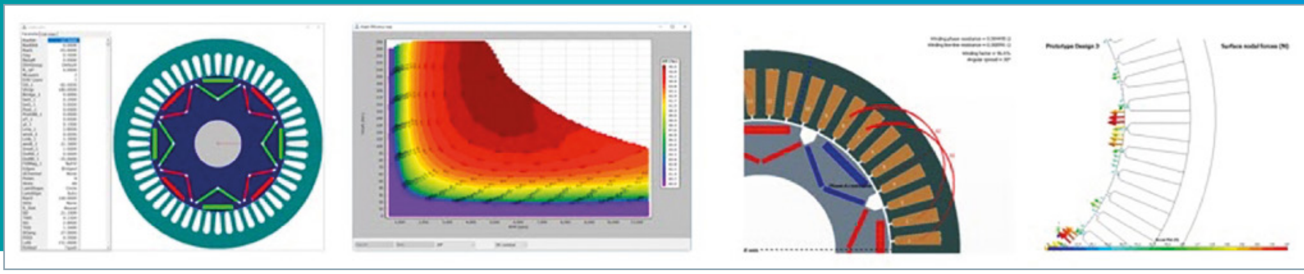


Figure 3: Analytic calculation-based efficiency map of an IPM motor using Simcenter SPEED (left) and surface nodal force distribution of a modified IPM using Simcenter Motorsolve

automated model creation (based on designer inputs of geometry, winding, materials, etc.) in a matter of minutes. The low overhead is essential for exploring a large number of design candidates quickly, while allowing for innovative and atypical topologies to be considered with respect to rotor and stator geometries, winding configuration, material choices and cooling system types. Aside from quick design exploration there are a number of important simulation capabilities needed at this stage.

Firstly, obtaining fast performance results are critical for evaluating various designs, a key objective at this stage. For this, magnetic circuit based semi-analytic models are ideal. Simulation tools based on this approach can calculate the complete machine performance characteristics in ~tens of seconds. However, as the number of candidates is reduced higher fidelity performance evaluations are required since modeling non linearities, slotting and other effects cannot be taken into account adequately using the magnetic circuits based approach.

A Finite Element Analysis (FEA) based simulation tool within a template based environment is ideal. In addition to standard motor performance results (torque, power, efficiency, torque-speed characteristics, etc.) an FEA based tool also calculates the machine iron losses, evaluates the effects of permanent magnet demagnetization, carries out coupled electromagnetic-thermal simulations to identify machine hot spots and calculates the surface nodal forces and their harmonics for NVH analysis.

To summarize, access to magnetic circuit and FEA based simulation tools in a template based interface provide the ideal platform for design space reduction, fast machine performance evaluations, accurate efficiency calculations, low fidelity multi-physics analyses and links to drive design and system level engineering tools.

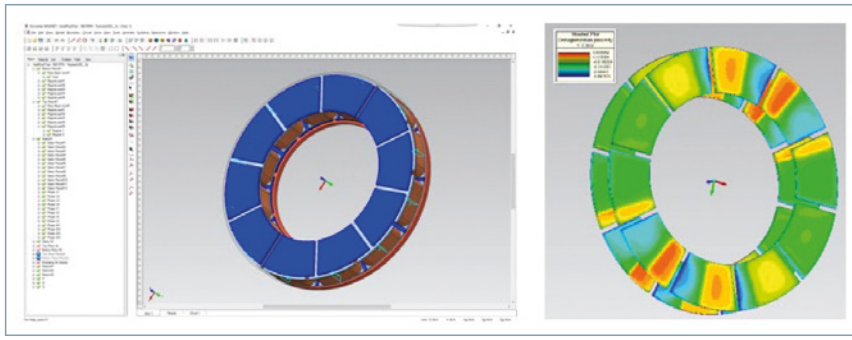


Figure 4: 3D demagnetization analysis of an axial flux motor using Simcenter MAGNET

Design validation and multi-physics analysis

Once a single or a few designs have been selected for further analysis, 2D and/or 3D simulations are carried out for validating the machine performance, refining geometries to optimize the flux distribution and reduce leakages, analyzing system faults including 3D demagnetization prediction, sensitivity analysis, coupled electromagnetic-thermal simulations, structural analysis and design optimization. From a software tools standpoint, at this stage the highest fidelity modeling methodologies are typically used. For most problems this implies FEA based tools.

The 3D FEA based tools used at this stage should utilize model reduction capabilities to minimize simulation times. This implies taking advantage of model symmetry, boundary conditions and the application of non-uniform or adaptive mesh settings. High Performance Computing (HPC) may greatly reduce the solution times of some problems as well (Litz wire modeling or for 6-DOF motion modeling problems). To obtain the highest accuracy level results and to ensure design robustness, hysteresis solver based electromagnetic field solutions and 2D/3D demagnetization modeling analysis are needed, respectively. The demagnetization modeling capability should be able to model the effects of minor loops and the recoil behavior of magnets due to elevated temperature or from system faults.

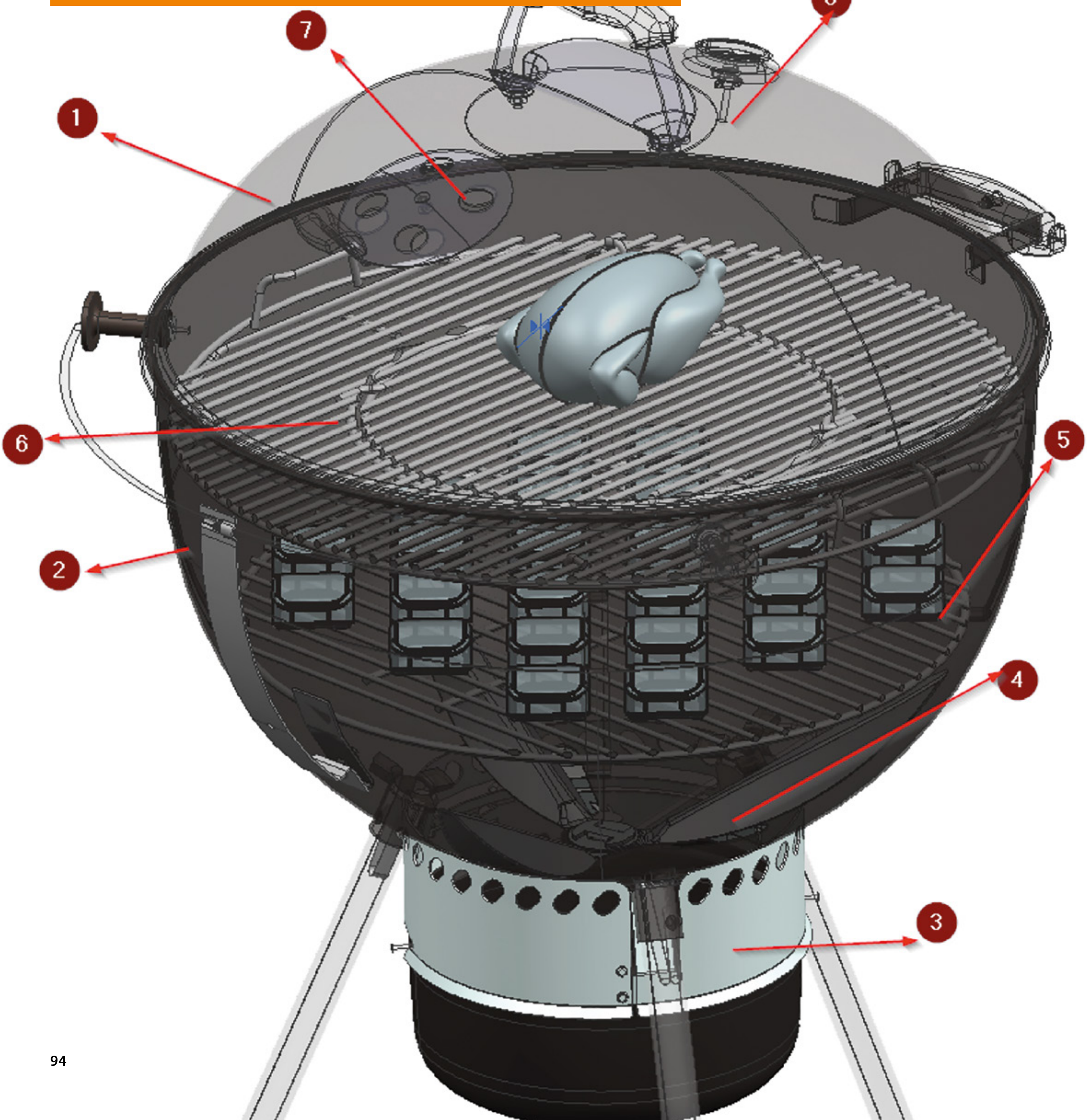
Once the electromagnetic performances have been validated, fully coupled EM-TH simulations are needed. Coupled simulations may be carried out using empirical heat transfer coefficient or CFD based approaches. For NVH and structural analysis, surface nodal and interface force information are exported from 3D models.

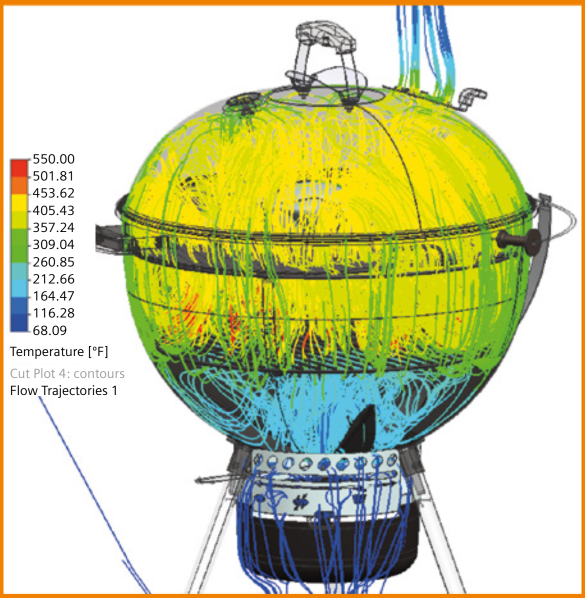
Overcoming the challenges

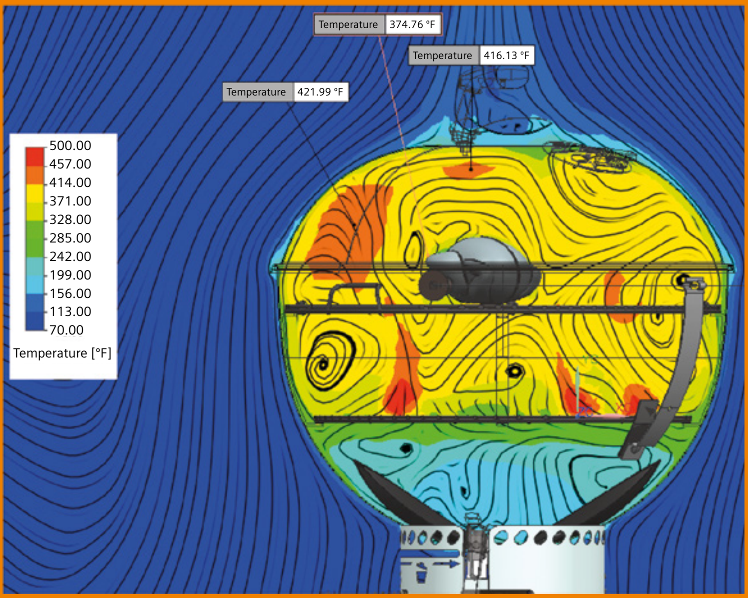
In this article the end-to-end electromagnetic design of a traction motor has been described focusing on the challenges faced by contemporary and future traction motor designers. A typical motor design V-cycle was used to highlight some of the main modeling capabilities needed to overcome these challenges. Advances in computational electromagnetics, the application of HPC to electromagnetic and multi physics simulation problems, state-of-the-art NVH analysis software and the connectivity between the different tools are helping to implement novel and innovative design paradigms and for creating state-of-the-art digital twins of traction motors. ■

Geek Hub

Cooking on a kettle grill using Simcenter FLOEFD. A grill getting too hot or too cold will be a thing of the past!







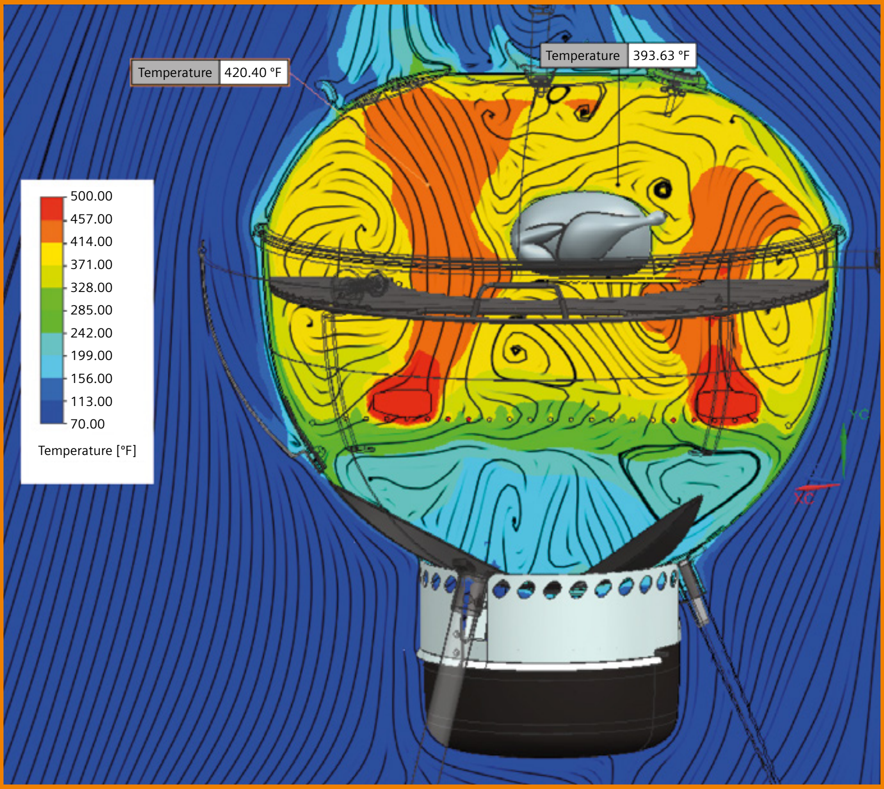
In pursuit of the perfect cook:
Almost all of us have cooked something on the grill ranging from meat to vegetables. It takes a long time to become a grilling expert and for a very good reason. Every grill has unique characteristics like shape, materials, coal placement, etc. Even the type of coal being used can drastically change grill performance from cook to cook.

The type of grill we will look at is a kettle grill; it has vents on the bottom for variable air flow, vents on the top to let hot air escape, and the coal is placed close to the bottom vents. A few factors that are very important when trying to achieve a good cook are even distribution of heat which will lead to even cooking, a good sear on food but also a desire not to burn the food. Grill masters go to various lengths in the pursuit of the perfect cook, some even have secrets that they aren't willing to share. Using Simcenter FLOEFD we will look at the performance of a kettle grill to see if we can reveal some of the secrets that grill masters hold dear.

The basics of a kettle grill:
Let us breakdown the construction of a typical kettle grill:

1. **Top lid –** This lid is typically made of steel and coated with paint. This lid also has a plastic handle to safely lift the lid.
2. **Bottom kettle –** This part has similar construction as the top lid. It has flanges for placing the coal racks and the cooking rack.
3. **Ash catcher –** Some kettle grills can hold ash when the bottom vent handle is slid back and forth.
4. **Bottom vents –** These vents allow cold air to enter in order to provide enough air for the coals to burn.
5. **Coal rack –** This is typically placed right above the bottom vent holes.
6. **Cooking rack –** This is placed above the coal rack.
7. **Top vent holes –** The hot air leaves the grill from these holes. These gases are combustion products from burning the coal
8. **Temperature probe –** This probe is typically used to judge how hot the grill is.

A few observations have been made after looking at the design. The temperature probe is placed all the way at the top of the grill. There could be a difference in temperature inside the grill which cannot be captured by the one temperature probe measurement. Some parts of the grill may be hotter or cooler than the temperature probe. The placement of the bottom vents and the top vents may also have an impact on the performance of the grill. Other factors that can cause variability in performance of the grill are: amount of food, placement of food, amount of charcoal, and placement of charcoal.



inside the kettle. For more information about the flow we will look at cut plots of velocity.

This image to the left, has been taken at the center of the grill. The section has been taken in a such a way that both vents have been avoided. In this section there is no air leaving or entering from the vents. The temperature distribution is quite uniform, we do see a few localized hot spots and they are about 45F higher than temperature near the chicken. This difference could become significant factor if the food is cooked for a long time.

The image below shows a section taken at one of the vents. We clearly see that distribution in this section is not very uniform. There are a few things that contribute to this, the bottom vents are placed directly below a few coal pieces. The top vent and the bottom vent line up, so, air can enter the bottom vent and leave through the top vent without circulating inside. This is the reason we a large hot spot starting at the coal and going all the way to the top vent. The left-hand side if this image shows the hot air leaving the grill, on the right-hand side there is still recirculation going on.

Assumptions and setup:
For this study, we will be using a uniform distribution of charcoal on the rack. Some research was completed to find out the temperature at which charcoal burns. Abhishek Vanaparti with Auburn University published a paper characterizing two types of coal (instant light vs. slow burning). The temperature of charcoal has been obtained from this paper. The temperature measurement was done when the charcoals reached a gray condition, typically charcoal is ready to be put on the grill once this condition is reached. We are also assuming that charcoal maintains temperature for the duration of our experiment.

The next assumption is regarding the material of the food being put on the grill. Since meat is made up of several different kinds of tissues and fibers, characterizing the material properties would have been a daunting task. For simplicity, one value of density, specific heat, and thermal conductivity have been selected to mimic the properties of chicken.

The grill has been placed in an open environment at an ambient temperature of 20C. The physics being considered are heat conduction in solids, radiation, and gravity. Radiation plays a big role in this study as a significant amount of heat leaves the charcoal in the form of radiation. Due to this, special attention has been paid to the emissivity value of the metallic components of this grill. The color of the top and bottom kettle has been assumed to be black. All metallic parts are assumed to be made of steel.

The analysis been split up into two steps, grill preheating and the cooking stage. This is done to mimic the way which food is typically prepared on the grill.

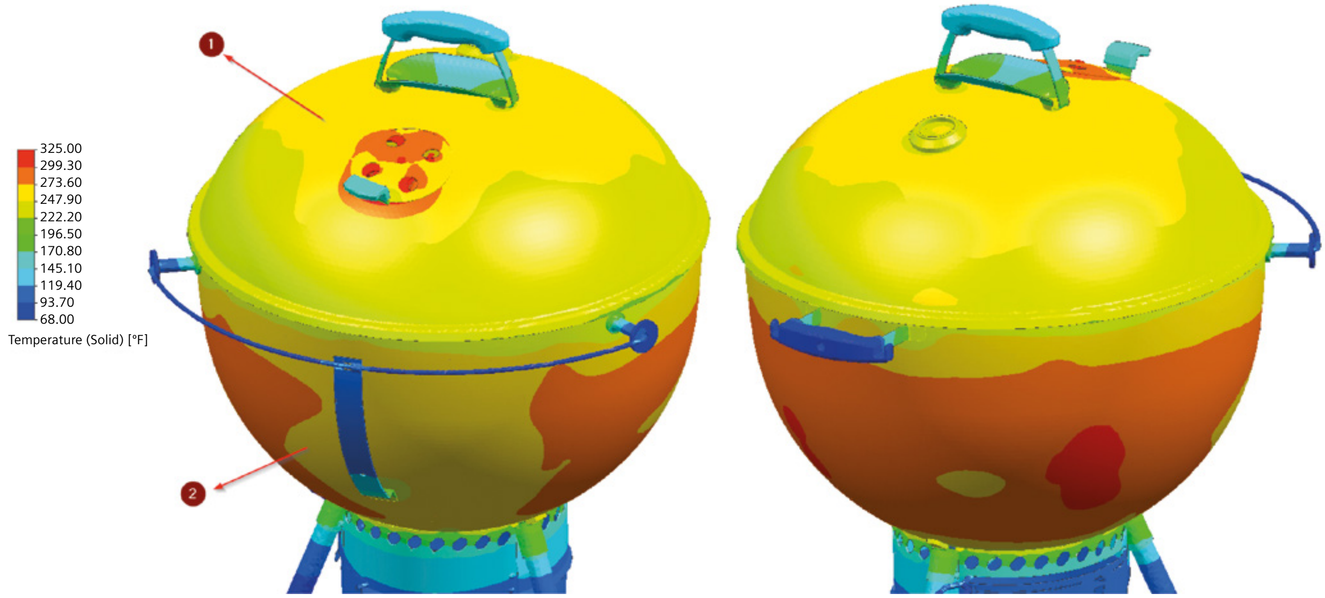
Results and findings:
Flow and temperature distribution inside the kettle:

To better understand the distribution of flow inside the kettle we will be looking cut plots and flow trajectories showing how air is moving within the grill.

By looking at the flow trajectories we can see that cold air enters at the bottom and circulates near the coal rack region. There is also a huge recirculation zone formed by the top cover of the kettle. This is a great design feature as more recirculation results in more even temperature distribution

Temperature distribution on the outside surface of the grill:
While looking at the image below we can see that the temperature distribution on the outer surface is not uniform. Hot air leaves through the top vents (1) and we can clearly see that region at a higher temperature. On the bottom kettle the lower vents are lined up with the top vents, so, when we look at that side of the grill, we see lower temperatures than the surrounding areas. This could be due to lack of recirculation or due to heat being dissipated via the metallic attachment (2) that is designed to hold the lid while opening the grill. The other side of the grill is shown below with the temperature probe visible, on this side the temperature distribution on the bottom grill is much more even.

Is the temperature probe a good metric for measuring grill temperature?
The temperature probe is typically used to measure the temperature of the grill.



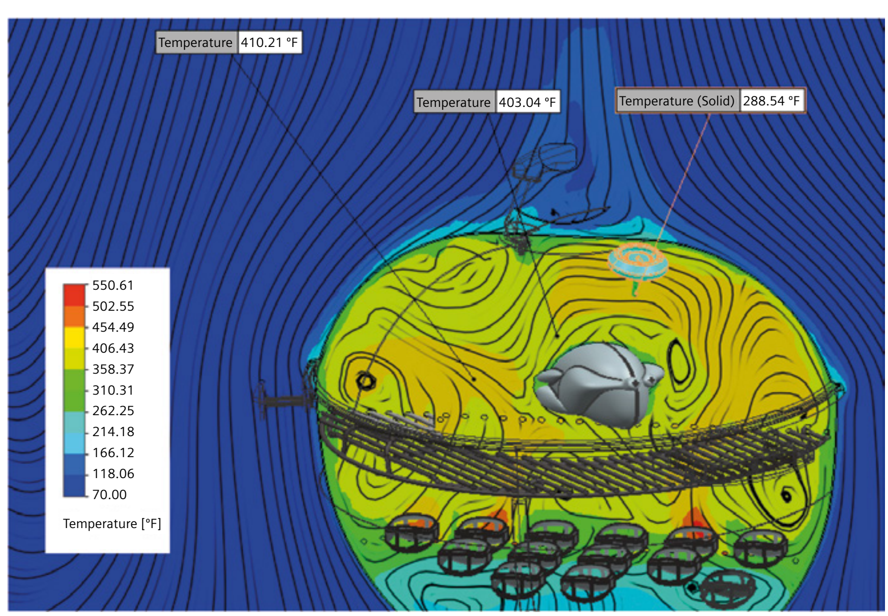
People assume that the average temperature inside the grill is the temperature of the probe. From the image below we can see that the probe is at ~290F but the temperature in the top kettle which has the food could be anywhere between 400-410F. This is more than a 100F difference in the measured vs the actual temperature.

Next steps and summary

Simcenter FLOEFD provides insight into the performance of this grill. Valuable information can be extracted from these results without having to do physical testing. These results offer a more in-depth analysis of the grill performance than that which can be achieved through physical testing. With Simcenter FLOEFD engineers can perform intelligent design exploration on existing designs to improve the performance. Various things like geometry, boundary conditions, constraints can be changed and things like temperature in certain regions, flow velocities in keys areas, etc., can be optimized for.

Some of the conclusions and possible next steps for this grill are as follows:

1. Temperature distribution inside the kettle is fairly uniform but there are some hot spots with higher that 40F difference than the surroundings. Even temperature distribution is desired in all regions of the grill. The placement of the top vents relative to the bottom vents could be responsible for this issue. Design exploration can be performed in order to vary the orientation of these vents to find the best arrangement of the vents.
2. There was some uneven temperature distribution on the outer surface of the lower kettle. This could be due to hot air escaping or the metallic attachments. Further work needs to be done to identify the cause of this temperature difference.
3. The temperature probe shows more than 100F lower temperature than some regions in the grill. A better approach would be to conduct multiple studies and find out a correction factor that can be applied to solve this discrepancy. Multiple temperature probes could also be used in order to get a better idea of the temperature distribution inside the grill. ■



Brownian Motion...

The random musings of a Fluid Dynamicist

The Human Race is Powered by Ancient Organisms. If we aren't careful, they'll kill us all.

I don't know about you, but one of my least favorite jobs is filling my car full of petrol (known as gasoline to our American readers). In the US, you can lock the trigger in place and means that you can detach yourself physically from the whole process. For us Europeans, that isn't an option. We have to keep the trigger depressed for the entire tedious filling process, the only fun bit is trying to hit a "00" on the pence (or cents) part of the price.

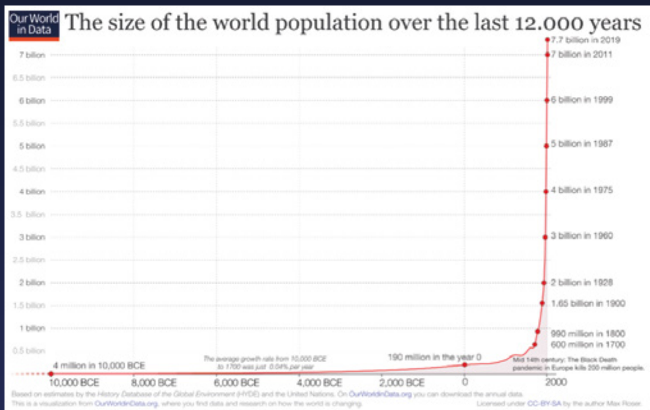
This often leaves me contemplating the origin of the hydrocarbons as I pump them into my tank. How they are basically the processed remains of living organisms that decomposed over millions of years. And how all the energy stored within those organisms will soon - after a brief glorious moment in which it is transformed into useful work - will be converted into useless low-grade heat. That whole process is a metaphor for the development of our species over the last 300 years.

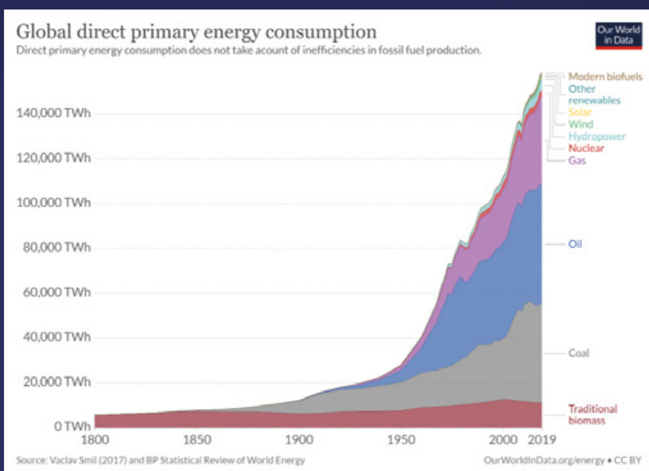
Since the beginning of the Industrial Revolution, humans have become increasingly dependent on the cheap and plentiful supply of energy. It feeds us, fuels our movements, keeps us warm in the winter and cool in the summer, and provides endless piles of disposable "things" that we use as a temporary substitute for happiness. Energy is the only universal currency. Those economies with access to the cheapest sources of energy (either through the fortune of geographical location or military conquest) are generally the wealthiest and offer the highest standards of living.

In 1700, before the start of the Industrial Revolution, there were only 600 million people on the planet (about twice the population of the modern USA), today the population of the world exceeds 7.5 billion. It took us 99.5% of our 300,000-year history as a species for the human population to exceed 80 million people. The world population now grows by more than that every year. The UN estimates that by 2056 the world population will exceed 10 billion people.

That growth is fueled by, and entirely dependent on the supply of cheap energy. In 2018 our species used 160 PWh of energy. An average healthy fit person can sustain about 100 W of manual work. Across a ten-hour working day, that's about 1kWh of work done. As a species, we generate (and therefore consume) about 60kWh of energy per person every day. So on average, each of us consumes 60 times more energy than we could possibly generate through manual labor alone. And that's a conservative estimate. Many of those people are too young or too elderly to deliver their 1kWh of energy. Many of us (especially in the West) also consume far more than our fair share of 60kWh.

About 87% of that energy used to fuel our species comes from the combustion of the decomposed remains of ancient

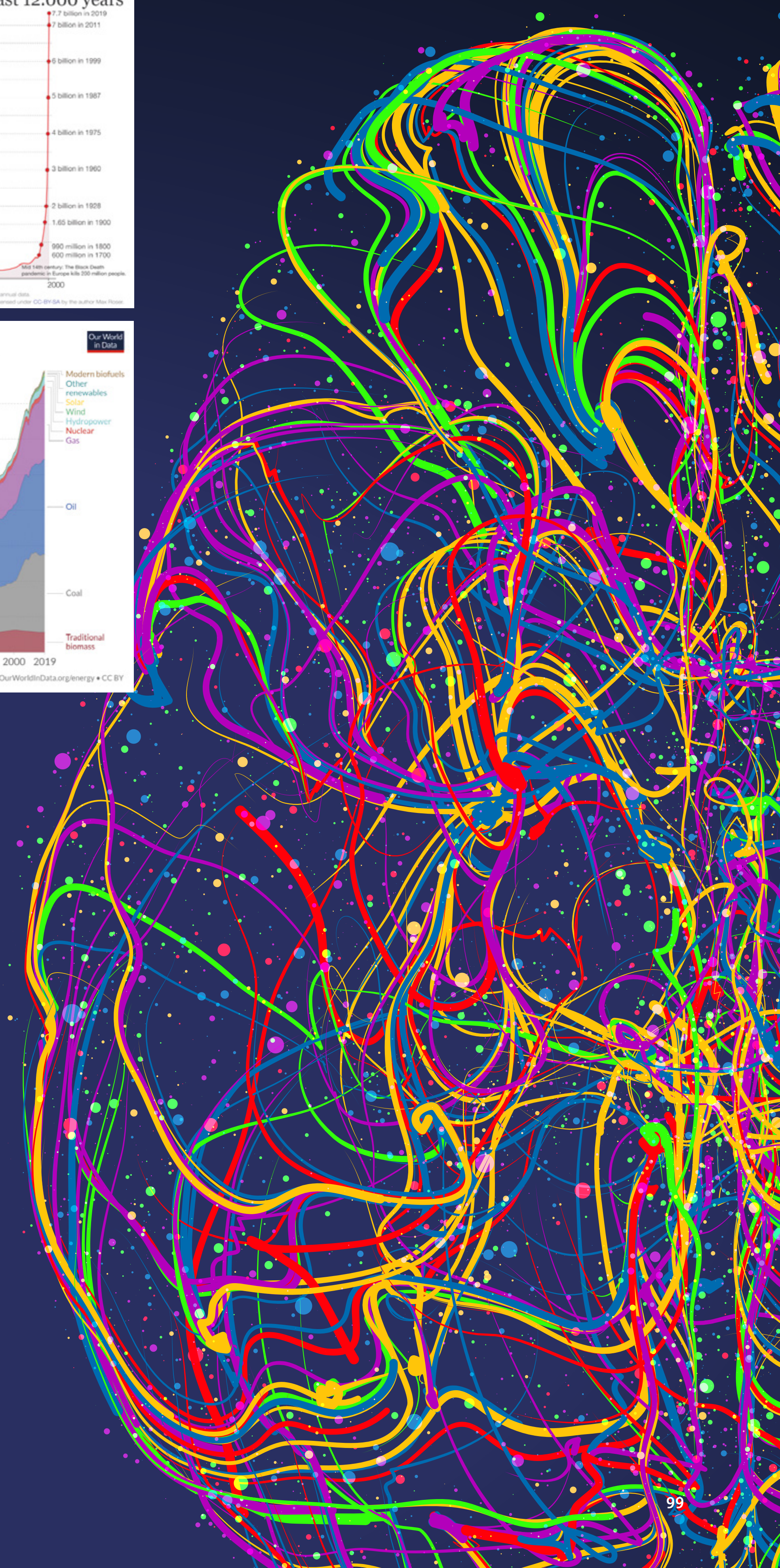




organisms (natural gas, crude oil, and coal). Supplies of those hydrocarbons are limited and burning them is a primary cause of climate change. As engineers and a society, we obviously have lots of work to do in finding sustainable alternatives to fuel the requirements of our energy-hungry species.

This is one of the reasons that I've recently decided to get rid of my gas-guzzling car. I might eventually replace it with an electric vehicle (for which the charging process is even more tedious than refueling), but for the moment, I'll try to walk and cycle instead. ■

*The chemical energy contained within the fuel is created to high-grade thermal energy by the combustion process. Most of this is wasted as heat, but some is turned into useful kinetic energy that propels the vehicle. That kinetic energy will ultimately be converted into low grade heat through mechanical friction (including braking) and aerodynamic drag, which will also be converted into heat by viscous friction. Some of the energy might temporarily be stored in the battery of the vehicle. The only way that I can think of to avoid converting ALL of the fuel energy to heat, is to drive your vehicle to the top of a big hill and leave it there (thereby permanently converting it to potential energy).



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