June 2021

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Simulation: WHAT'S AHEAD?

DigitalEngineering247.com

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By Brian Albright

Join us at CAASE21

ALTHOUGH THE WORLD HAS LOOKED VERY DIFFERENT in many ways over the past year and a half, and many traditional activities have been on hold for what seems like a lifetime, one thing has not slowed down: the rapid pace of innovation in the engineering sector in general, and in the simulation space in particular.

The use of simulation earlier and more often during the design cycle continues to expand. Simulation software providers continue to increase the features and functions in their products, and to offer new types of licensing arrangements to make them easier to use. New cloud-based simulation products have increased the democratization of simulation. Disruptive technologies like electric vehicles, autonomous aircraft, robotic manufacturing, and sustainability innovations require greater use of simulation than ever before.

That is why I have been looking forward to the launch of our second online Conference on Advancing Analysis & Simulation in Engineering (CAASE21) event, which Digital Engineering and our partners at NAFEMS Americas will present on June 16.

The first CAASE was a live event in 2018, followed by a successful online conference in 2019. The COVID-19 pandemic forced a switch from a live to a virtual CAASE20 event last year. Although a return to in-person conferences is still a ways off for most of us, the upcoming online CAASE21 conference will give us all a chance to reconvene and catch up on the latest advancements in simulation, design and additive manufacturing technology.

In conjunction with NAFEMS Americas, we have put together a one-day program with presentations on the use of simulation for developing autonomous driving systems, methods of validating simulation results, additive manufacturing standardization, and digital twin innovations. You can learn more and register for the conference at the CAASE21 website. You can also check our preview coverage on page 8.

To provide further insights into the leading edge of simulation technology, we have put together a lineup of stories that will help engineers navigate this rapidly evolving landscape. Jim Romeo takes a look at the use of artificial intelligence and machine learning in simulation and manufacturing, while Senior Editor Kenneth Wong investigates test-based validation for simulation results.

We also take a look at multi-material simulations for additive manufacturing applications, and the use of open-source simulation tools.

The End of the Tunnel

Last summer at this time, I was adjusting to a work (from home) environment and the thought of a highly restricted list of summer activities.

In-person industry events may be back at some point this summer or fall, but so far AMUG has been the only major conference to welcome back attendees. Since last June, we have made multiple visits to the kitchen of NVIDIA CEO Jensen Huang, who has made a point of welcoming virtual guests to the NVIDIA GTC conference series from his home. I am still not sure when I will get to see our readers in person, but I am hopeful it will be soon.

While the pandemic continues to wax and wane (sometimes dramatically) around the globe, there are signs that increased vaccinations and basic virology may finally bring this slow-rolling tragedy to a close.

My own children are back to playing (safely distanced) soccer and baseball. The economy is tentatively reawakening alongside the spring flowers here in the U.S. Many of our readers are returning to their offices, or navigating a new mix of remote and in-person work.

I remain amazed at how well and how quickly the people in our industry (both our readers and technology vendors alike) responded to the challenges of 2020. Across the board, we saw you all rising to the occasion, both to make the remote work transition as successfully and seamlessly as possible, and to use your own know-how and technologies to try and help others in need.

I look forward to interacting with you (virtually) at CAASE21.

Brian Albright, Editorial Director
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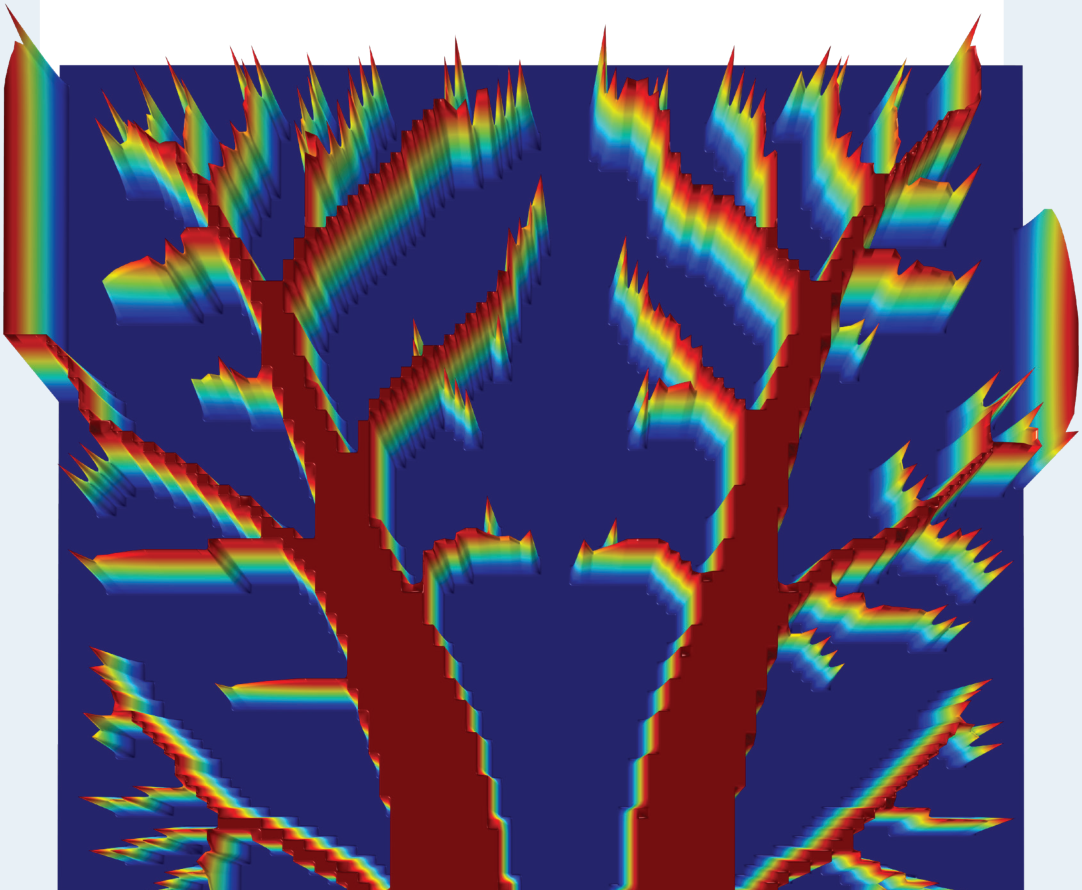

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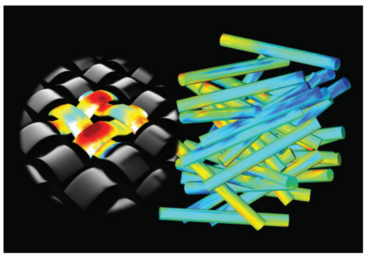
INSIDE

FOCUS ON SIMULATION REVOLUTION



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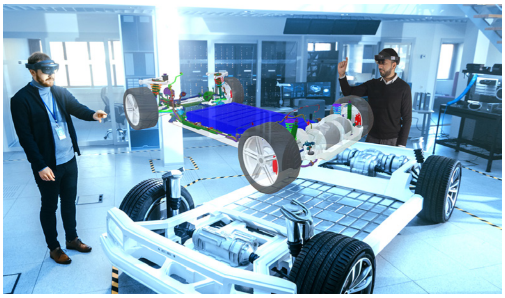

Editor's Pick, page 50

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BY THE NUMBERS | SIMULATION REVOLUTION

$26.93 BILLION

The size of the **SIMULATION SOFTWARE MARKET** by **2027**

Market in **2020**
$11.52 BILLION

12.9% expected **CAGR**

Source: Brandessence Market Research, March 2021

$70 BILLION

The size of the industrial **AUGMENTED REALITY MARKET** by **2025**

15+ MILLION

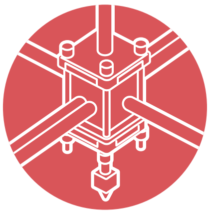
Estimated number of **SMART GLASSES** devices that will be used in industrial workflows

Source: ABI Research, AR in Industrial Applications, April 2021

"COVID-19 did not create the need for digitization, but it certainly accelerated it. As a high-value element of digitization, augmented reality adds a visual element to a data-heavy system that can sometimes devalue the human worker. AR brings the worker back into the equation and creates a synergistic relationship between worker and IT/OT systems where each component benefits from the other."

—ERIC ABBRUZZESE, Augmented and Virtual Reality Research Director at ABI

3D Printing Grew Despite COVID



How did COVID-19 affect your 3D printing usage?

It had **NO EFFECT** and stayed the same	**50%**
It **INCREASED** my usage	**33%**
It **DECREASED** my usage	**17%**

Source: 3D Hubs survey, conducted February 2021

$19 BILLION

The amount manufacturers will spend on industrial **INTERNET OF THINGS** data analytics by **2026,** according to ABI Research

A survey by 3D Hubs found that, despite the global pandemic, the **ADDITIVE MANUFACTURING MARKET** grew **21%** in 2020 (to $**12.6 BILLION**) and will grow by **17%** annually over the next three years.

Last year, **65%** of engineering businesses increased their usage of **3D PRINTING** and **54%** increased their use of the technology for functional **END-USE PARTS.**

Source: 3D Hubs, Additive Manufacturing Trend Report, April 2021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NEWS

SIMULATION

CAASE21: Simulation in Focus

The online conference will explore the use of simulation and analysis across the design and development process.

CAASE21
The Conference on Advancing Analysis & Simulation in Engineering
Online Event • June 16, 2021

The Conference on Advancing Analysis & Simulation in Engineering (CAASE) returns on June 16 with an online event featuring the latest advancements in simulation and analysis.

In 2018, Digital Engineering first partnered with NAFEMS Americas, the association for the engineering modeling, analysis and simulation community, to present the CAASE for the very first time in Cleveland. That was followed by two virtual events in 2019 and 2020.

CAASE21, a one-day event, will feature sessions led by representatives from Rolls-Royce, George Mason University, Purdue University, the National Institute of Standards and Technology (NIST) and the University of Texas at Austin. CAASE21 will follow the same format as CAASE19, with the conference keynote available live and online starting at 1 p.m. ET, followed by four additional presentations beginning at 2 p.m. ET.

"CAASE keynotes have always represented the best of a thought-provoking simulation-driven future, aimed at creating a sound understanding of newer and increasingly relevant advancements," says Matthew Ladzinski, vice president of operations at NAFEMS. "We are incredibly fortunate to have some of the best minds in the industry sharing their expertise in the areas of engineering analysis and simulation related to Automated Driving Systems & 5G, Systems Engineering & Robust Design, Verification & Validation, Digital Twins and Additive Manufacturing."

CAASE21 provides attendees a glimpse of the simulation-driven future in a series of web presentations from leading experts and end users. Without even leaving their desks, attendees will learn about the latest trends in engineering analysis and simulation, how industry leaders are using simulation, what lessons they've learned along the way and how the industry can democratize simulation to increase adoption.

We've designed the conference to be equally appealing to simulation novices as well as more experienced engineers, with a focus on business benefits and challenges that can help users better evaluate the potential ROI as they consider how to more extensively deploy simulation into their design and development processes.

Keynote: Challenges of Fully Integrating Sensor, Vehicle ADS, and 5G Technologies to Achieve Reliable and Safe Transportation Systems

Duminda Wijesekera

Cing-Dao (Steve) Kan

As sensor, vehicle auto-drive-system (ADS), and 5G communication connectivity technologies advance, the future transportation system in the U.S. could potentially benefit from optimized roadways, reduced emissions, less congestion and fewer traffic fatalities.

Keynote speakers Professor Cing-Dao (Steve) Kan and Duminda Wijesekera from George Mason University will discuss the reliability of key technology in sensing, vehicle ADS and 5G connectivity, as well as their integration into future transportation systems. Some of the main challenges of transitioning to fully automated vehicle fleets on U.S. roadways will also be discussed so that engineers are fully aware of the safety consequences of this technology evolution.

Track 1: Stochastics, Robust Design and Systems Engineering to Support Simulation-Driven Design

Alexander Karl

The digital engineering strategy of the Department of Defense, the drive to develop and use digital twins, and several Certification-by-Analysis activities are driving the need for more simulation-driven design. This could potentially shift work from the physical environment into a virtual or digital environment, leading to significant reduction in the resources needed to design, produce, and keep aerospace assets operational.

In this session, Alexander Karl, associate fellow, Robust Design and Systems Engineering, Rolls-Royce Corp., will discuss the application of automated design and simulation processes, robust design techniques and probabilistic and stochastic methods for real-world design tasks in the area of advanced gas turbines. The talk will close with a discussion of the challenges in the area of simulation-driven design.

Track 2: Towards Demonstrating Simulation Credibility in Industry: Are We There Yet?

As the availability and complexity of simulation models increase, more organizations have recognized the importance of simulation governance to help ensure the reliability and proper use of numerical simulation tools. To meet this demand for improving credibility, organizations must show adequate evidence that the models are reliable and credible for their intended use.

In this session, Jakob Hartl, PhD student, Aerospace Systems, at Purdue University will provide an overview of a rigorous, structured verification, validation and uncertainty quantification (VVUQ) framework used to analyze a 3D centrifugal compressor aerodynamic model that was performed as part of a collaboration between Purdue University and Rolls-Royce.

Jakob Hartl

He will also discuss the challenges of this type of analysis, and the benefits of demonstrating simulation credibility.

Track 3: Supporting the Simulation Community by Building a Broad-Based Additive Manufacturing Infrastructure

Lyle Levine

Additive manufacturing (AM) of metals is a rapidly growing manufacturing approach, but there are still challenges around reproducibility, reliability and performance of AM components. Continued adoption of AM will require broad-based infrastructure-development investments, and many of these are focused on the critical role of computer simulations.

The National Institute of Standards and Technology (NIST) is heavily involved in these AM infrastructure-development efforts. In this session, Lyle Levine, senior physicist at NIST, will describe the group's role in areas such as qualification and certification (Q&C), validation, benchmarks and measurement standards. He will also discuss the role that NIST plays in developing AM-focused measurement capabilities and standards that underlie efforts to improve reproducibility and reliability of AM components.

Track 4: Digital Twins: From Physics-Based Modeling to Scientific Machine Learning

This session, led by Karen Willcox, director of the Oden Institute for Computational Engineering and Sciences at the University of Texas at Austin, will discuss the ways in which digital twins have the potential to transform design, manufacture and operation of engineering systems.

Karen Willcox

To make digital twins a reality, many elements of the interdisciplinary field of computational science, including physics-based modeling and simulation, inverse problems, uncertainty quantification and scientific machine learning, have an important role to play. Willcox will present a probabilistic graphical model as a formal mathematical representation of a digital twin and its associated physical asset. She will also demonstrate how the approach is instantiated to create, update and deploy a structural digital twin of an unmanned aerial vehicle.

For more information and to register, visit www.digitalengineering247.com/caase21.

Explore CAASE

The Conference on Advancing Analysis & Simulation in Engineering (CAASE) was launched by Digital Engineering and NAFEMS in 2018. The first online event (CAASE19) followed. While CAASE20 was planned as a live conference, the global pandemic forced a rapid (and successful) shift to a virtual event.

You can still explore the archived conference content from CAASE19 and CAASE20 at the links below.

www.digitalengineering247.com/caase19

www.nafems.org/events/nafems/2020/caase20

The Coming of Age of **AI** and **Machine Learning** in Design

Simulation and manufacturing can benefit from AI, but adoption hurdles still exist.

BY JIM ROMEO

Design and simulation software tools are increasingly incorporating artificial intelligence (AI) and machine learning (ML) to accelerate engineering design performance and aid in decision-making and design space exploration.

As these and other applications are used, the engineer has many potential benefits, along with sone challenges of incorporating the technology into the design cycle and further applying AI in other areas of the manufacturing process.

The tools need to be accurate, easy to use and very efficient. In addition, people have traditionally worked in siloes, working on specific physics with less familiarity of multiphysics coupling to solve complex problems. Designers don't traditionally communicate with the people doing the manufacturing. This technology encourages a more inclusive, collaborative environment. *Image courtesy of MSC Software.*

A New Era of Design?

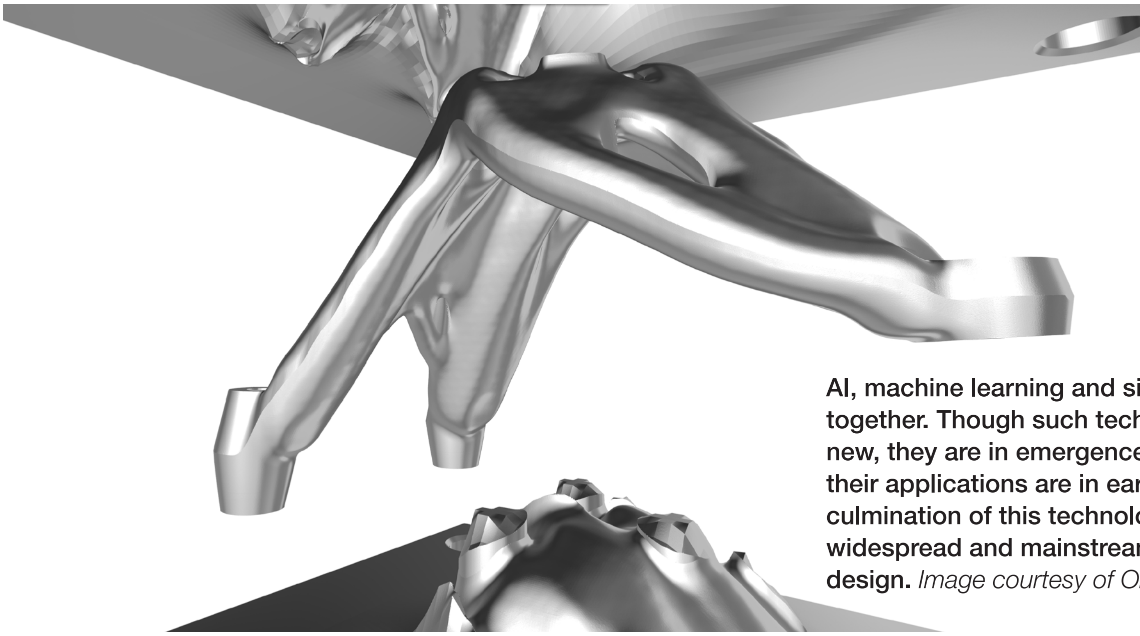
"AI simulation is ushering in a new era of design and computer-aided engineering where AI will leverage data, predicted or measured, to push virtual engineering to the next level," says Roger Assaker, CEO of MSC Software, part of Hexagon's Manufacturing Intelligence division. "What used to take days or weeks can now be accomplished much quicker, often within minutes or hours.

"Leveraging AI and machine learning can produce simulations that cut significant time off the design and engineering (D&E) processes by validating designs quickly and efficiently," Assaker says. "It also acts as a democratization tool as it exposes non-experts to the design possibilities in an easy-to-understand format. It opens the world of simulation to non-finite element experts."

Greg Brown is a product management fellow at Onshape. He joined PTC in 1997 as a simulation specialist. He believes that AI and machine learning (ML) are a suitable combo, but have struggled to live up to their practical value until this point.

"Simulation has roots back to the beginnings of digital computers, and approaches such as finite element analysis have been employed for half a century or more, especially in aerospace applications," Brown adds. "However, even as the precision and breadth of physics being considered has exponentially risen, the mainstream engineers in consumer products, heavy industrial and to a large extent automotive industries have, in my opinion, been underserved."

The "holy grail" for software vendors, according to Brown, has always been to tap into the sizable designer simulation market, and to date, for whatever reason, this



AI, machine learning and simulation go together. Though such technologies are not new, they are in emergence and many of their applications are in early adoption. The culmination of this technology will manifest in widespread and mainstream use of generative design. *Image courtesy of Onshape/PTC.*

has eluded most attempts.

"On the other hand, a confluence of technologies that have emerged in the last couple of years (including graphics processing unit based solvers, cloud and SaaS implementations and accessible AI and ML) could change the game for designer simulation," he notes.

FEA and Reduced Order Models

Larry Williams is a distinguished engineer with Ansys who says the use of finite element analysis (FEA) has been instrumental in solving problems with unprecedented accuracy. Such use falls in sync with the benefit of algorithms and optimization for generative design.

"Our electromagnetic analysis and structural analysis finite element solvers have long used automated procedures to refine the finite element mesh where needed," Williams says. "The software has built-in indicators to identify locations to place additional elements into the mesh as demanded for ultimate accuracy. This results in accurate solutions while minimizing compute memory resource requirements and simultaneously speeding solutions."

Williams explains that another mature example of ML in simulation is the generation of accurate reduced-order models (ROM). Ansys's non-linear ROM technology brings physics-based detailed simulation models when near instantaneous results are needed.

"The higher level of accuracy and wider range of applicability that these non-linear ROMs achieve relative to conventional ROMs are a result of the innovative use of neural nets and other ML methods in the training and derivation of the ROMs," he says.

Challenges In Using AI and ML

Adam Weaver is a manager with Fluids Engineering Solutions at Rand Worldwide. He emphasizes that related software applications are tools, but there's still cognitive interaction required to apply them properly.

"First and foremost is the education of users on the workflows that need to be implemented. Simulation in general requires an understanding of advanced physics, numerical process and quantification of uncertainty, among other things. The scripting of optimization methods demands an even tighter grasp," Weaver says.

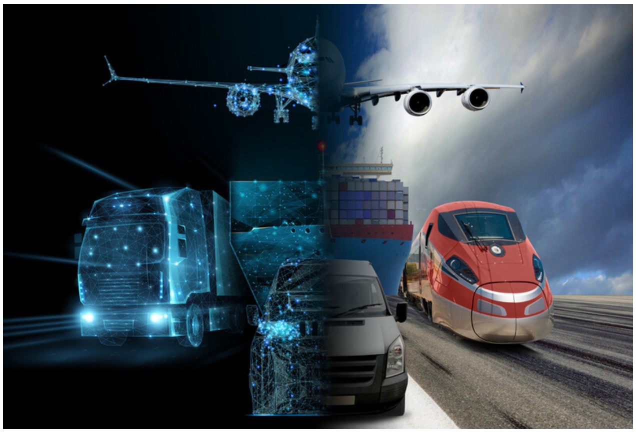
"As a result, the field tends to be sown with doubt any time it is being used by those without the proper experience level," he adds. "Simply put: the tool greatly improves our ability to design, but it will not build the house for you. In this analogy, the inherent difference is that people have come to accept that hammers cannot build homes, but they tend to think simulation automatically solves problems; when they see inaccurate simulations, they often blame the tool, not the person wielding it."

Weaver says there's still room for growth and improvement in the use of simulation tools, while noting significant strides as simulation undergoes democratization.

"As the tools are further developed, the learning curve is dropping and the barrier to entry is coming down slowly. Correlatively, more academic focus is being applied on these fields, leading to a workforce more suited for this type of work," he says.

Xun Jiao is an assistant professor in the Department of Electrical and Computer Engineering at Villanova University. He narrows the challenges down to two significant ones in using AI, ML and simulation technology tools.

"Two challenges exist: the accuracy—developing a model that can describe a very complicated physical process accurately can be quite challenging. Traditionally, people use physics-based modeling methods such as analytical modeling but now people started to use more and more AI methods for modeling in a data-driven way," says Jiao. "[Then there's] the speed—simulation can be quite slow, depending on the level of detail the simulation is trying to capture."



Applying AI and machine learning to real-world sensor data and physics-based simulation data produces accurate, predictive models of a product at efficient compute power levels. *Image courtesy of MSC Software.*

He provides an example of simulating the functional correctness of a chip under varying workload environments and operating conditions, which can be slow. He also describes a recent paper that he was part of that proposed an AI/ML-based model to serve as an alternative to conventional simulation tools, which, according to Jiao, "achieves over 50X speed up, with high accuracy."

Some of the additional challenges in embracing AI and ML relate to the availability and access of such tools.

"This approach is computationally intensive," says Chris Nicholson, CEO of Pathmind. "Ideally, you have some form of elastic compute that allows you to run many experiments at once. That is, you need easy access to infrastructure. The latest AI tools are not available with all design software. It can be hard to find the right tooling stack that integrates with everything you need. In addition, sometimes engineers don't have the training required to succeed with AI."

Focus on Benefit

Despite the challenges, the benefits of employing AI, ML and innovative simulation software applications are many. This combination acts in tandem to streamline and expedite workflows, while shortening design timelines and reducing costs.

Gleb Gusev is the chief technology officer at Artec 3D, manufacturer of 3D hardware and software. He highlights the benefits of how new technologies such as AI and ML improve testing, while meeting specifications and coming up with solutions—all at a lower total cost.

These new technologies offer "a faster iteration and design process, as your design is created mainly by algorithm with only the constraints for your requirements added by hand," says Gusev. "It is easier and cheaper to test as you will already have viable solutions that will satisfy your requirements and will therefore require less prototyping.

"You are able to explore a wider range of possible design solutions as AI can generate many solutions that won't be limited by your personal experience and expertise," Gusev adds. "You can then explore and improve on these solutions."

Raghi Iyengar is president of DSi-Digital's Manufacton and ViZZ products, which are used in construction design. He points out that software applications may be collaborative and used by a dispersed workforce, which allows others in the supply chain to collaborate.

"The biggest benefit of AI and simulation, with products such as ViZZ and Manufacton, is the continued effort to productize construction with complete visibility and access to project data," he says. "Through accessing insights around prior supply chain relationships and product experiences, the industry is better equipped to make construction projects faster, cheaper, better and greener."

There's also the cost savings reaped from cost avoidance in physical testing and running the systems.

"This is the real opportunity: reduce the cost of testing and running systems by doing more of the testing on software, rather than in the real world. More accurate, dynamic and highly dimensional simulations can model more potential instantiations of a product in the real world, avoiding costly tests that only serve to find out failure points," says Ash Fontana, managing director of Zetta Venture Partners.

AI, ML, and Simulation—Looking Forward

MSC Software's Assaker expects these new technologies to continue to influence and disrupt manufacturing. Manufacturing is seemingly becoming smarter with each new release and the momentum is growing.

"AI and ML complement physics-based simulation per-

AI and ML complement physics-based simulation perfectly. AI and ML are revolutionizing manufacturing. Smart manufacturing is where the industry is headed, according to MSC Software. *Image courtesy of MSC Software.*

fectly. AI and ML are revolutionizing manufacturing," says Assaker. "Physics-based and data-based simulations capture data that physics-based models alone can't capture fast or accurately enough. We see a future in which all elements of the manufacturing processes are working together to create the optimum solution through leveraging AI- and ML-enhanced simulations and modeling."

Ansys's Williams says he is confident in the future and expects deep learning to usher in a new era of simulation that will disrupt nearly every industry.

"Augmenting the solvers via deep learning, simulation tools will improve how engineers innovate new products, allowing them to deliver products to market faster than ever before while cutting costs," he says. "Augmenting the applications with simulation will enable much more comprehensive training and hence more rapid adoption." DE

Jim Romeo *is a freelance writer based in Chesapeake, VA. Send e-mail about this article to de-editors@digitaleng.news.*

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A Reality Check for Simulation

Simulation needs test-based validation to be credible.

BY KENNETH WONG

In theory there is no difference between theory and practice, while in practice there is.

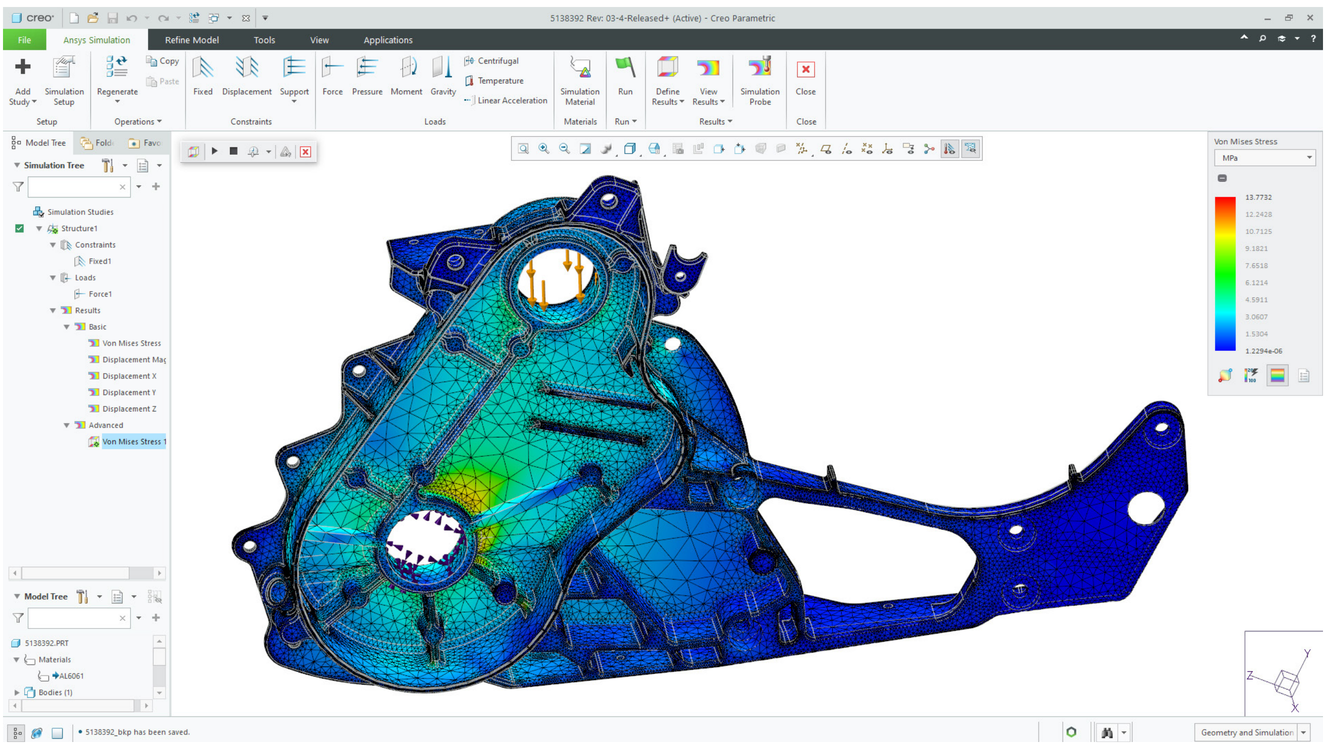
This quote has been attributed to Yogi Berra, Albert Einstein and Richard Feynman, but credible sources that link them to the quote are rare. Its unverifiable origin aside, the quote is a good reminder for the engineering industry that has been relying more on digital simulation to make design decisions.

How important is the peculiar bending mode that a new type of plastic exhibits in heat? Is it wise to dismiss it in the simulation setup? Is it overkill to spend time and money to scrutinize the phenomenon in a testing lab to quantify it? These decisions all come down to a simple act of balance, the experts say.

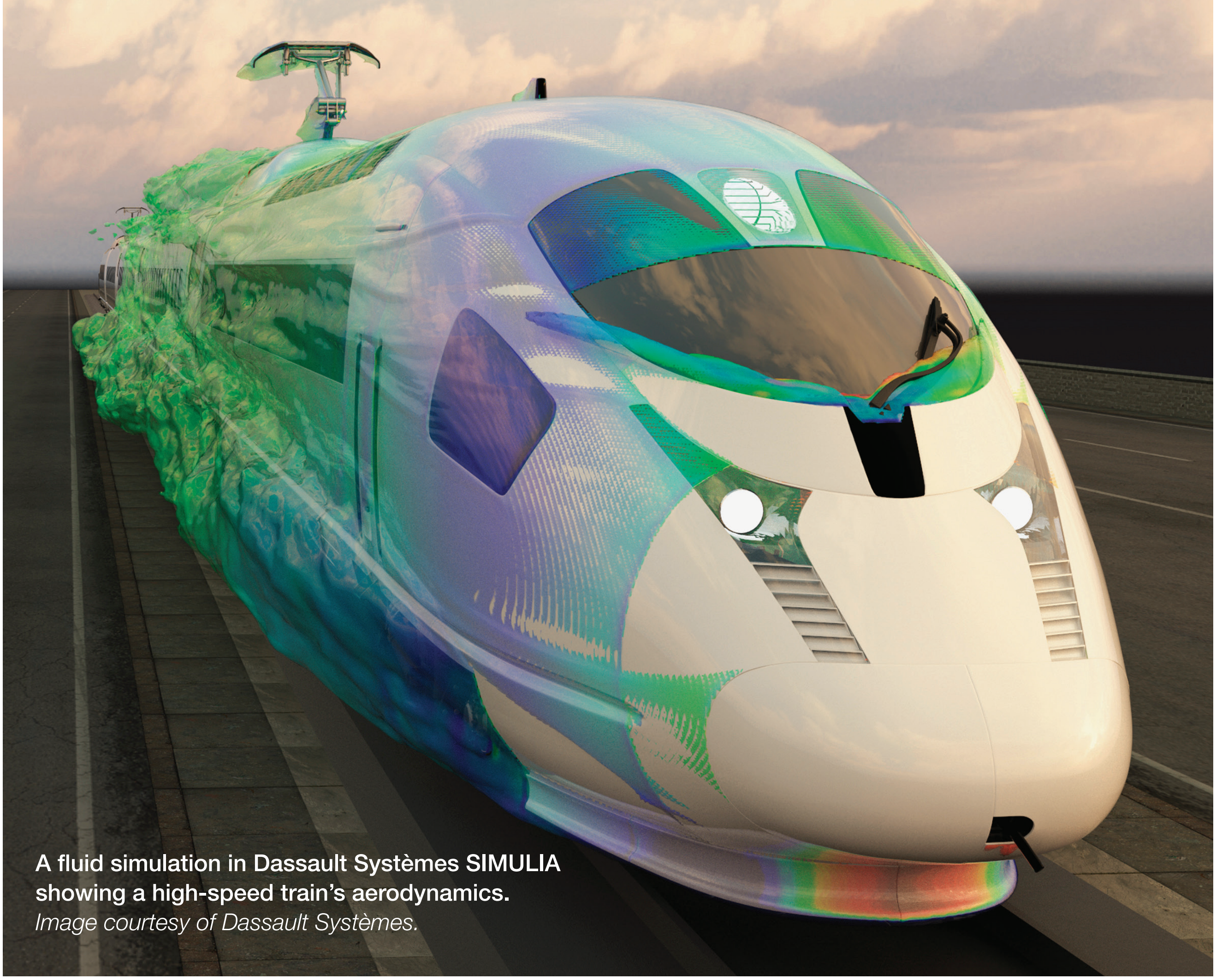
A U.S. $6.1 Billion Market

Jakob Hartl, a Ph.D. student and graduate research assistant at Purdue University, is planning to speak on "Application of a Verification and Validation Framework for Establishing Trust in Model Predictions" at the upcoming CAASE21 virtual conference (June 16, 2021; digitalengineering247.com/caase21), co-produced by DE and NAFEMS.

"Computer simulation is a more cost-efficient and faster way to acquire information than traditional methods of experimentation, so it's gaining adoption," he says. "But compared to real-world tests, computer-based simulation is a relatively new field of science."



A partnership between PTC and Ansys resulted in PTC Creo Live simulation aimed at designers. *Image courtesy of PTC.*



A fluid simulation in Dassault Systèmes SIMULIA showing a high-speed train's aerodynamics. *Image courtesy of Dassault Systèmes.*

That new field of science has spawned a robust computer-aided engineering (CAE) software industry, generating $6.1 billion in 2020, according to a Cambashi analyst. The market offers digital solutions for simulating everything from acoustics behavior, thermal events and manufacturing processes to failure modes. The top three vendors—Ansys, Siemens and Dassault Systèmes—accounted for 47% of the total 2020 CAE software market, according to Cambashi.

During the 2017 NAFEMS conference, Patrick Safarian, Federal Aviation Administration's Fatigue and Damage Tolerance senior technical specialist, revealed that "Certain regulatory requirements allow analytical approaches to be used for compliance purposes as an option to testing. In all cases these regulations require validation of the analysis before the results can be accepted."

But he also noted "the reliability of these solutions [analytical approaches] is always a major concern."

Automotive and aerospace, the two industries that heavily leverage digital simulation, are dominated by a handful of titans pursuing similar projects in the race against one another—autonomous vehicles, for example.

"A bunch of organizations are probably doing the same type of work and studies in validating their simulations. It would move faster if everyone were willing to share, but of course, they cannot because of competition," says Hartl.

Relatively Reliable

In different products and different phases of the design, the consequences of design failure vary. In finite element analysis (FEA) terms, the damage to a smartphone's outer shell and internal components and the failure of an airplane's landing gear are quite similar. Both can be represented and simulated with a blend of structural and electromechanical solvers. But the consequences of failure are significantly different. Therefore, the simulation reliability, or the desired level of accuracy in the digital model, should be judged accordingly.

"If you are using the model to make high-consequence decisions, involving human lives or financial loss, then you obviously need to be more rigorous," warns Hartl.

Contrary to what people might deduce from his upcoming technical talk about using uncertainty quantification and numerical methods to boost trust in simulation, Hartl is a fan of simpler digital models providing a wider range of applications.

"I prefer simpler models to complex, expensive models, as long as you take the time to understand what your predictions mean, and the errors in them," he notes.

Material Matters

Tim Whitwell, VP of Engineering at Tectonic Audio Labs, cares a lot about what he hears. He and his team use COMSOL Multiphysics to build simulation models to analyze the inner workings of Tectonic's Transducer devices.

A fluid simulation in Dassault Systèmes SIMULIA showing waves interacting with offshore windmills. *Image courtesy of Dassault Systèmes.*

"We conduct dedicated motor, suspension and diaphragm bending studies in addition to fully-coupled analyses of the whole transducer," he says.

For him, the choice between digital simulation and physical testing is also an act of balance. "There are times when we can get the answer we're looking for more easily with a physical test," he says. "I can spend two weeks building a simulation model and validating it, but with modern rapid prototyping tools, like 3D printers, I can build a prototype and test it in three days."

On the other hand, with components like the spider corrugated suspension element, the digital model is the only choice. "These components in the drive unit require tooling, so you can't use rapid prototyping," he explains.

For Tectonic's simulation needs, standard material definitions are not always enough. "Rubber under dynamic conditions behaves very differently from under static conditions," he explains. "You can get the data for rubber from a lot of public sources. That may be OK if you're using it for refrigerator doors, but in our speakers, it's oscillating 10,000 times a second, so the tensile stiffness is very different."

Tectonic runs its own testing lab to recreate the operating conditions of its products and measure the materials' stretching and bending behaviors.

"A digital model is good for preliminary assessments, but if we want to put more trust in the model, we have to measure the sample materials under the conditions they will be used," he says.

Material calibration is also part of simulation software from Dassault Systèmes' SIMULIA brand. It's a feature that has served the tire industry. This is a critical tool for modeling nonlinear elasticity, stiffness damage and viscoelastic behaviors found in tires.

"In short, the material calibration app lets you take experimental data and use it to replicate any material's behavior," says Anders Winkler, portfolio technical director, R&D Strategy, Dassault Systèmes. "So in your simulation, the material models describing the material behavior produce more accurate results."

High Fidelity versus Low Fidelity

In general, CAE users tend to think of a higher mesh-count as high-fidelity simulation, but that's not necessarily the case, says Rachel Fu, portfolio technical director, R&D Strategy, Dassault Systèmes.

"High fidelity means taking the approximations out of the simulation," she says. "For simplicity, you might assume certain parts behave linearly, as opposed to nonlinearly. You might assume certain parts are clamped down rather than fastened with fasteners. High fidelity means removing these simplifications."

Simplified—or low-fidelity simulation—has a purpose too, especially in the conceptual phase.

"You can conduct lower fidelity simulation with faster run times, then have the simulation results dictate what your design should look like. Simulation-based optimization at the conceptual phase will become the norm," Fu says.

With on-demand computing power, small and midsized firms can also afford to run high-fidelity simulation once accessible only to industry titans with proprietary HPC (high-performance computing) servers. But Winkler worries about a side effect.

"That goes against the fiber of green software," he points out. "If you run more simulation on bigger clusters, it generates a lot of heat, so it needs more cooling, which in turn increases power consumption. Converting server halls into heat-power-generating units is certainly one of the more rewarding engineering challenges of our time."

Winkler thinks the complexity and sizes of the digital simulation models are beginning to test the limits of FEA itself. "On a 10- to 15-year horizon this puts healthy pressure on us [software developers] to collaborate even tighter with academia to see how different types of numerical methods evolve to increase accuracy and speed in simulation," he reasons.

High-fidelity simulation powered by on-premises or on-demand HPC costs money, but it's not the only cost. "It costs time," says Todd Kraft, CAD product manager, PTC. "If you run the simulation at 50,000 elements, you might get the answer in 5 minutes. But with 2 million [or more] cells with advanced connections and physics, you may have to wait a day or two. It's common to run coarse-mesh simulations early on."

In 2018, at PTC's LiveWorx Conference in Boston, the company announced a partnership with Ansys, to deliver Ansys Discovery Live real-time simulation within PTC Creo software. What Ansys developed—a faster, easier simulation aimed at designers—was a departure from classic simulation paradigm. The graphics processing unit (GPU)-accelerated code with direct modeling contributed to near-real-time interactive response, promoting a more liberal use of simulation among the designers.

This allows PTC to offer a simulation tool called Creo Simulation Live that targets the conceptual design phase to complement the company's other analyst-targeted simulation products in the Creo portfolio.

A Historical Record

What are the chances that, 20 years later, someone might want to consult a simulation run you conducted today? Perhaps not in the use-and-toss electronics industry, but in the infrastructure, automotive and aerospace sectors where product lifespans are much longer, this is more common than you might imagine.

"Keeping track of the loads, requirements and specifications for the case, perhaps even the specific digital machine involved or the regulatory compliance demand, is paramount. It has to do with traceability," says Winkler. "Storing all that information in a file system is a nightmare. It has to be a data model that can carry all that information with complete interoperability. That way, you can take the results from one analysis and continue working on them in a different scenario without adjusting or simplifying it."

Combining Simulation and Testing

With the advent of internet of things, embedded sensors are becoming the norm, finding their way into not only vehicles and planes but also washing machines and refrigerators. This represents a boon for simulation professionals that want ways to recreate a product's behaviors more accurately.

"Instead of just using a standard test, the question is, how do you better capture lifecycle loads?" asks S. Ravi Shankar, director of simulation product marketing, Siemens Digital Industries Software. "You need to think about the different types of load cases for your washing machine. Some based on routine usage, some based on possible misuse, but you cannot wait to capture 10 years' worth of data before you do the simulation. With our Simcenter software, you can perform mission synthesis to create an accelerated test profile that represents what a washing machine experiences over its lifecycle.

"On the other hand, simulation models can also augment test data for better engineering insights. Our software includes technology to create virtual sensors, so you get data in regions where a real sensor is difficult to place" he explains.

For Siemens customers, Teamcenter, the company's data management software is where test and simulation data converge. "By bringing together the design, simulation and test data to create a validation sequence [in Teamcenter], you can be confident that they all represent the same version of the design," Shankar says.

Measuring Uncertainty

Physical test remains the gold standard in full system validation, but there are scenarios where the capacity for physical testing is severely limited.

"In the fields of nuclear or satellite, for example, you can't do all the physical experiments you may want to do, so simulation and uncertainty quantification is extremely important," notes Shankar.

All simulation-based predictions involve uncertainty but "you can create an environment where you can say with numerical certainty that, these results, in this context, have 'x' percentage of reliability," says Winkler.

Uncertainty quantification is a discipline unto itself, supported by a brand of specialized software makers. SmartUQ, for example, offers solutions to address data sampling, design of experiments, statistical calibration and sensitivity analysis.

Don't Forget the Human-in-the-Loop

The one surefire way to increase simulation reliability without increasing model mesh count or server cost is with a careful choice of the CAE user, many suggest.

"It's important to understand the event you're modeling, the physical phenomenon you are trying to capture," Hartl says.

Arnaud van de Veerdonk, product manager, PTC echoes this sentiment.

"When validating the final design, it's important to have a simulation professional correctly apply the real-world loads and interpret the results. With the wrong assumptions, the model still gives you an answer, but that doesn't necessarily match what's happening in the real world," he says. **DE**

Kenneth Wong *is DE's resident blogger and senior editor. Email him at de-editors@digitaleng.news or share your thoughts on this article at digitaleng.news/facebook.*

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Studying Ants and Plants to **Build Better Parts**

Examine the link between generative design software and biomimicry.

BY KENNETH WONG

It may be true that it has never crossed your mind to seek advice from pheromone-driven ants and light-seeking plant cells when designing an aerospace or automotive component, but if you are using generative design software to sculpt your part, you might actually be doing it already. The Airbus bionic partition, a showpiece that demonstrates how Autodesk's generative technology was used in aerospace, achieves its weight-reduction goals by reusing the elegant patterns found in slime mold and mammal bones.

The developers behind Autodesk's Project Dreamcatcher and Desktop Metal's Live Parts revealed the generative algorithms in the software were inspired in part by how ants use pheromone to signal one another, and how plant cells gravitate toward sunlight for best access to nutrients. People often describe generative design's output as "organic," but this similarity to nature is often unintentional, the developers note.

The true link between biomimicry and generative design is how some software employs the logic found in nature to reap its benefits. Biomimicry, they argue, is less about replicating natural shapes and more about copying nature's problem-solving methods.

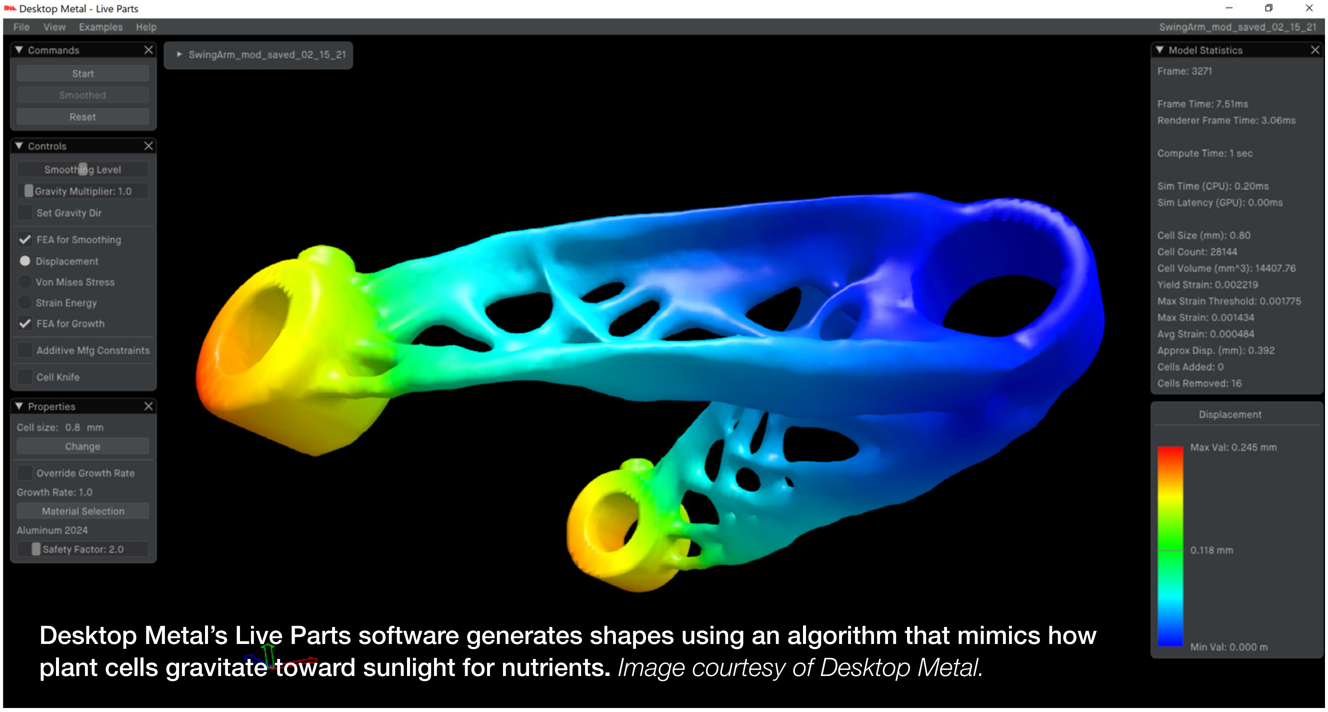
From Second Life to Live Parts

Live Parts, Desktop Metal's additive-focused generative design software is the brainchild of Andy Roberts, technical fellow at Desktop Metal. The algorithms underlying Live Parts, he reveals, were inspired by trees—not real trees but digital trees constructed of voxel-like cells.

"I was looking at Second Life. And I started to think, if these virtual worlds take off, people would be buying virtual trees and cars."

The online community Second Life has a thriving commerce system founded on the in-game currency Linden dollar. Many Second Life members with content-creation skills

Spinal implants designed using Autodesk's generative design technology, inspired by the way termites signal one another using pheromones. *Image courtesy of Autodesk.*



Desktop Metal's Live Parts software generates shapes using an algorithm that mimics how plant cells gravitate toward sunlight for nutrients. *Image courtesy of Desktop Metal.*

run virtual shops, selling everything from virtual clothes to virtual real estate to other Second Life inhabitants. To sell virtual trees, Roberts would first need to determine how to quickly generate trunks, branches and foliage.

"The way we draw things in CAD with lines and arcs is insufficient for that. That got me thinking [that] maybe we need a CAD system that grows materials where needed, similar to the way nature grows organisms," he says. "That was the genesis of Live Parts."

The growth model is ideal for additive manufacturing (AM) as 3D printers produce shapes by depositing materials. But what type of simple, elegant self-directed growth logic would satisfy the purpose of engineers working with shapes to counteract stress loads?

"I looked at how plant cells respond to external stimuli, like chemicals from light. So I have cells in Live Parts reacting to stress and strains, then spawning additional cells, called child cells," says Roberts.

Nature's construction materials are highly adaptable, whereas man-made materials are not. Steel is consistently dense; ceramic is brittle and plastic is elastic. Parts made of these exhibit the source materials' attributes throughout their entirety. On the other hand, many natural objects exhibit adaptive density, elasticity and brittleness in different regions for multiple purposes (think of the mix of muscles, veins and bones).

"Nature's materials are continuously changing in elasticity, density and brittleness. In the future, there will be lots of interest in materials with microlevel transformation," says Roberts.

Desktop Metal had been concentrating on metal-based 3D printing but early this year, it signaled a change. In February, in a $300 million cash-and-stock transaction, the company completed the acquisition of EnvisionTEC, which produces 3D printers that use photopolymers, ceramics and other materials.

"The company is a pioneer in digital biofabrication additive manufacturing with its Bioplotter platform, which supports the production of biocompatible parts for medical applications such as bone regeneration, cartilage regeneration, soft tissue fabrication, drug release and organ printing," according to the acquisition announcement.

The Lunch that Launched the Dreamcatcher

Nanda Santhanam, chief architect, Generative Design Project at Autodesk, recalled a lunch meeting in the early 2010s at the Autodesk University gathering that sowed the seed for what would later become Dreamcatcher, the first preview of the company's generative design technology. Dreamcatcher eventually evolved to become Autodesk Fusion 360's generative design tools.

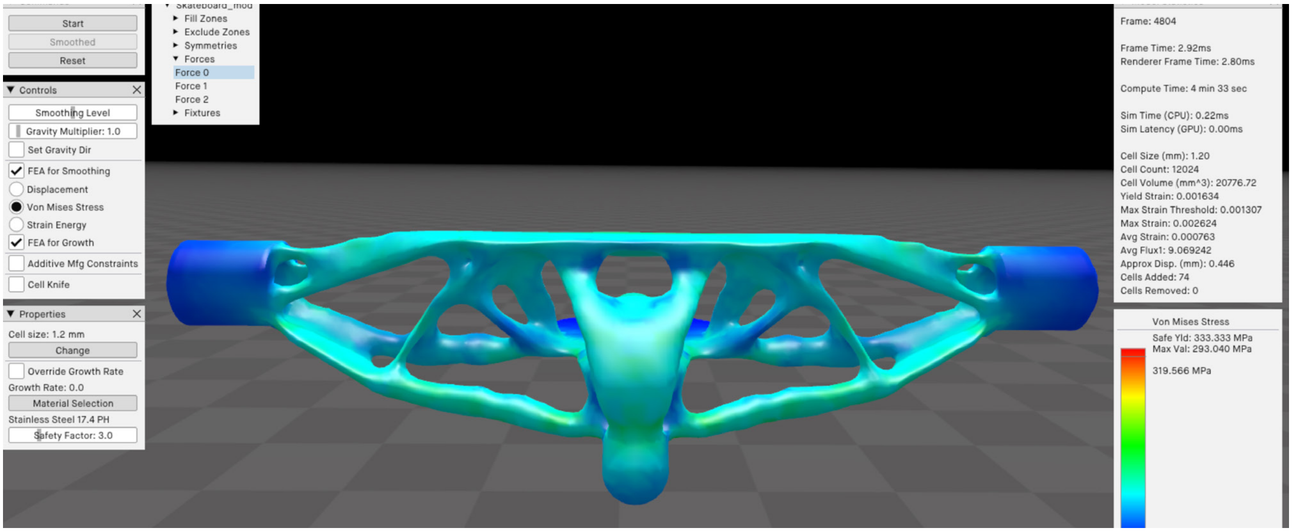
In the case of Autodesk, ideas in generative design were inspired by a bottoms-up approach in biomimicry. It came from "the termite nests, and the way the termites use pheromones to signal one another," says Santhanam. In the software, "we create stress or pheromone gradients. The core approach is quite simple, but the results are complex."

With such nature-inspired logics at the heart of their generative algorithms, generative design programs are bound to produce organic shapes from time to time, marked by asymmetry and complex surfaces. But the current manufacturing methods are no match for mother nature's factory, perfected over long stretches of time.

"In many cases we are dealing with much simpler manufacturing processes. We cannot completely replicate the complex biological systems," says Santhanam.

However, there's one aspect of nature that software developers have gotten better at replicating—its multiphysics behaviors.

"Look at the human body. We can have a single component that facilitates fluid flows as well as structural outcomes," says Santhanam. "There are similar activities in aerospace. For example, engines that combine fluid flow and



A skateboard wheel bracket designed in Live Parts. *Image courtesy of Desktop Metal.*

structural function. But this is not quite mainstream in generative design yet."

Santhanam also revealed his team has worked on frame-generating systems that could potentially be targeted for commercial release in the future. "It has some biomimicking elements," he says.

Looking Beyond BREP

Bradley Rothenberg, CEO of nTopology (nTop), often uses images of bird bones in his presentations but he hesitates to describe generative design as biomimicry.

"When I saw bird bones, I didn't say, 'I'm going to write an algorithm to topologically mimic this structure.' My first thought was, 'How am I going to represent that in 3D?' That's what got nTop started," he explains.

CAD modeling programs in general use BREP (boundary representation) to depict parts destined for production. But the method is not easily adaptable to organic shapes (such as human and animal physiognomy). For these, 3D modelers usually turn to mesh- and polygon-based software. The two methods don't blend well, which is why character animators won't typically use CAD programs to do their job. Mesh models, too, have a limit. With complex shapes, the file size dramatically increases, causing challenges in loading and editing.

"nTop is based on implicit modeling. How we represent 3D shapes, in some cases, is thousands of times faster and lighter than a CAD file, and the complexity doesn't break the system," says Rothenberg.

In its product description online, the company writes, "There are no 'black boxes.' nTopology gives you complete control over every aspect of your generative workflows, optimization processes and their outputs. Create reusable workflows that are tailored to the unique requirements of your application. Control designs at every point in space using simulation results, test data, engineering formulas and field-driven design."

Thinking Beyond Shapes

George de Mestral, the inventor of Velcro, was inspired by the cockleburs that clung to him and his dogs after taking a walk. ("A Mind-Blowing Biomimicry Example," July 2020, www.velcro.com). He borrowed the hook system found in the burs to create the Velcro's sticking mechanism for nonplanar surfaces. This is a case where biomimicry reaps the benefit by replicating the shape found in nature, but shape-based biomimicry doesn't always produce the best outcome, experts caution.

"Duplicating natural shapes is the low-hanging fruit, if it has more to do with capturing the aesthetics and less with the benefits and functions of the system itself," says Santhanam. A better approach, he suggests, is "to look at the underlying foundational mechanism that drives the creation of the biological system."

"Bird bones make sense in a bird that flaps its wings and flies. But if I want to build a chair, that's not a useful structure. It's all about solving an engineering problem," says Rothenberg. DE

Kenneth Wong *is DE's resident blogger and senior editor. Email him at de-editors@digitaleng.news or share your thoughts on this article at digitaleng.news/facebook.*

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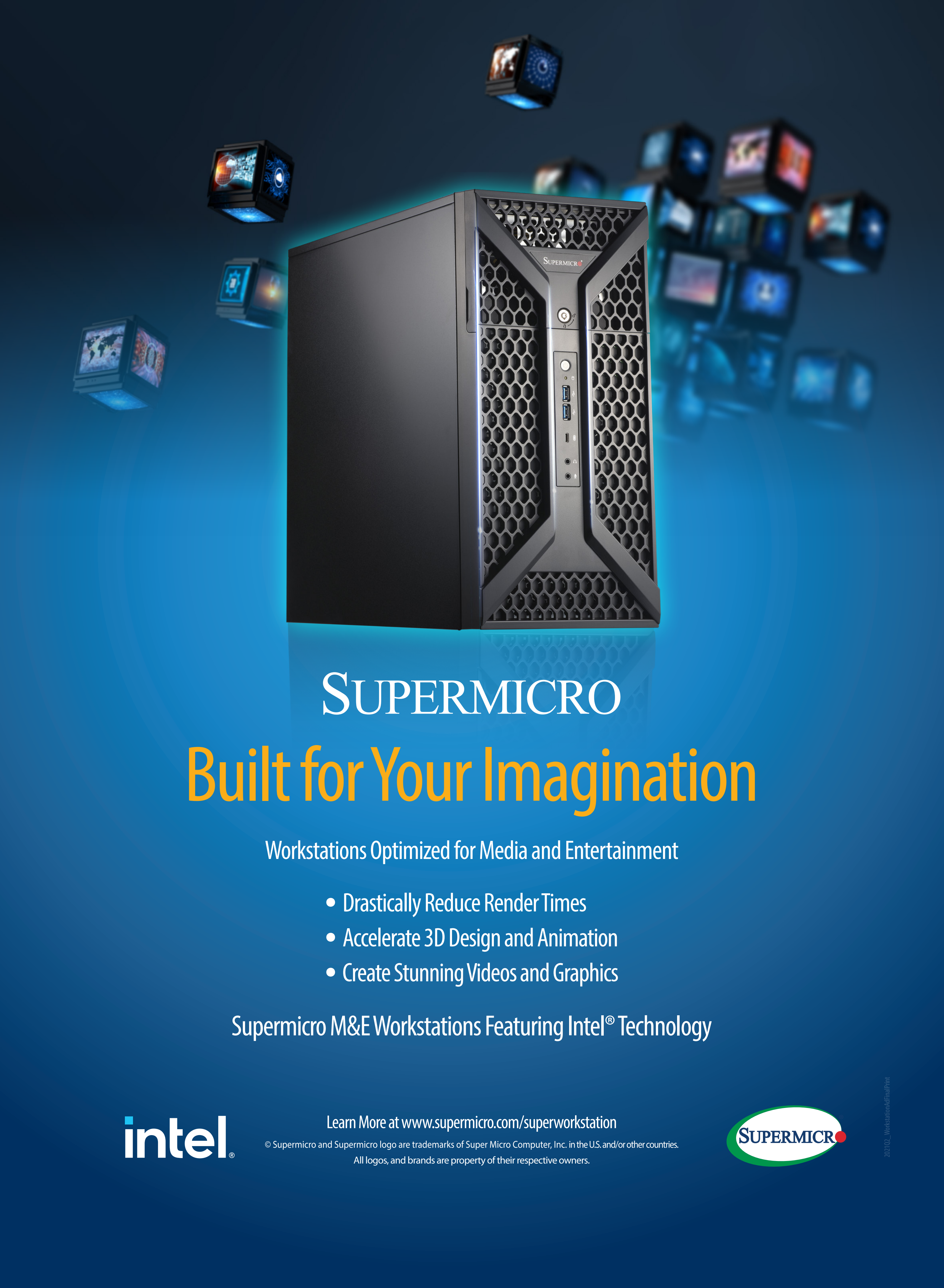
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SUPERMICRO

Open Source Meets Simulation

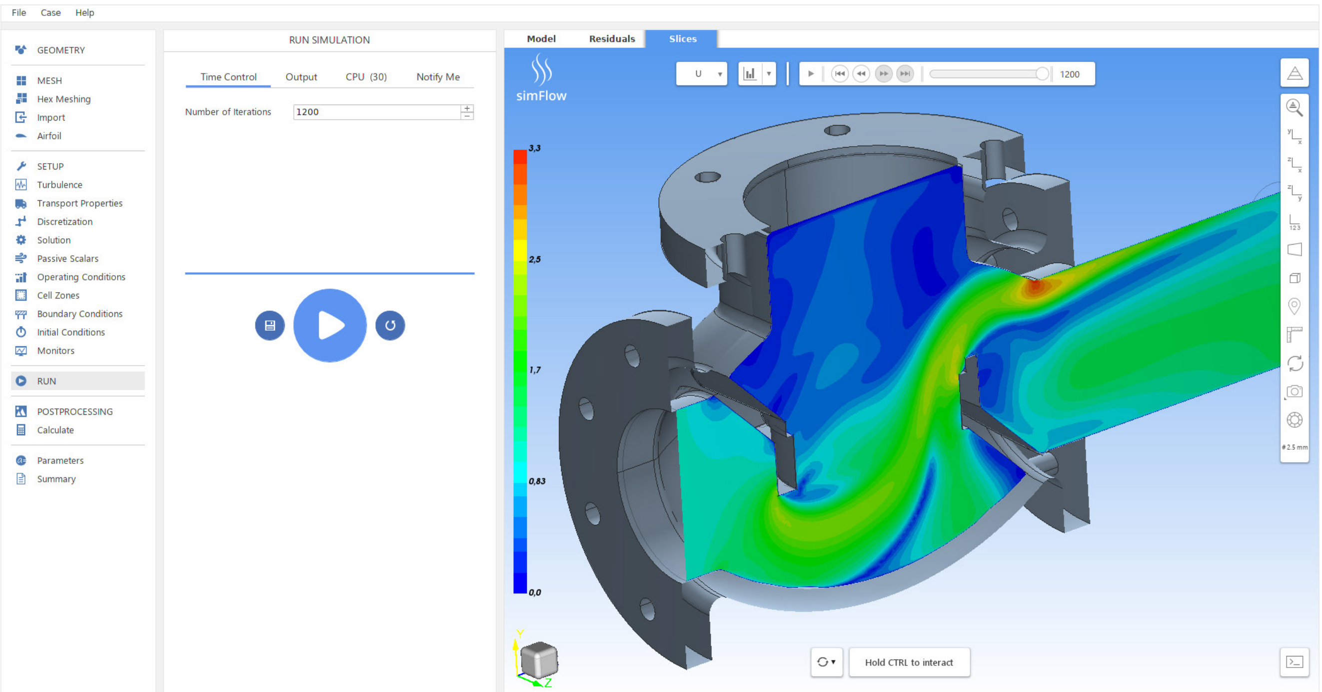
Open source CAE can be more cost effective and provide greater transparency than commercial simulation codes, but the learning curve is steep.

BY BETH STACKPOLE

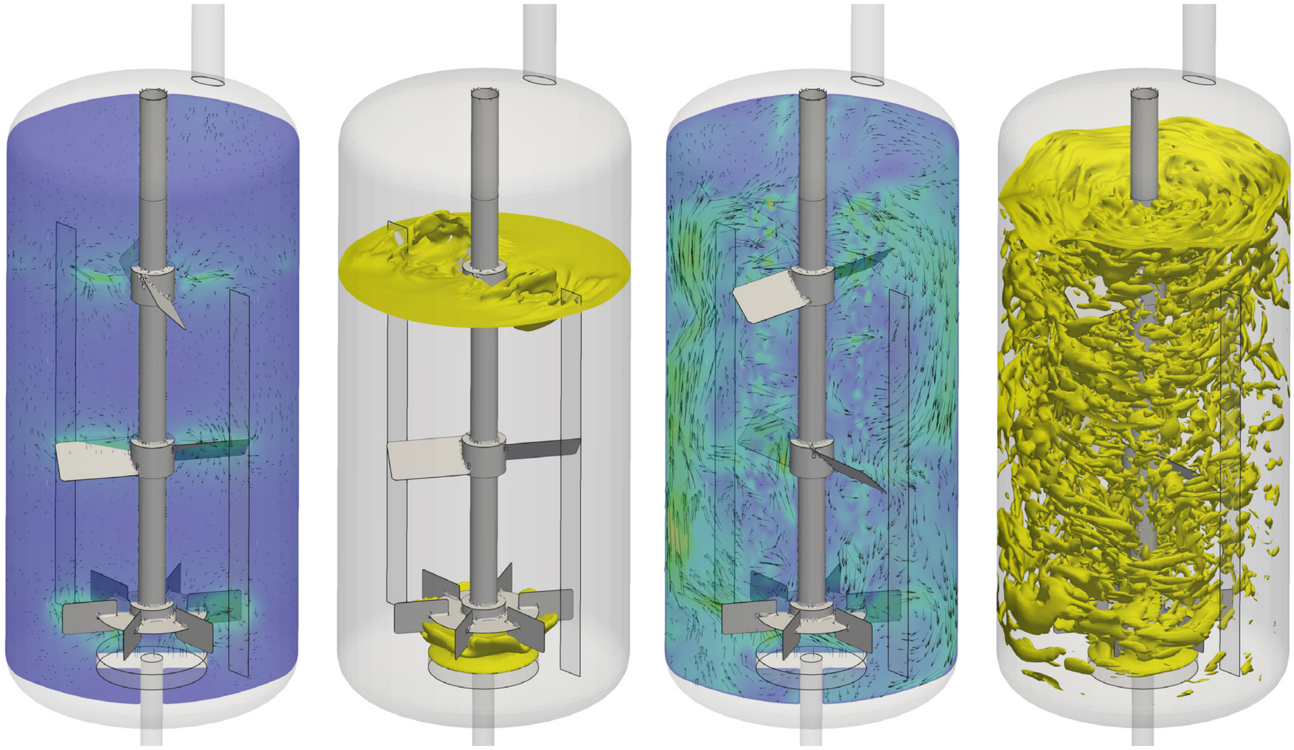
Simulation is fast becoming a familiar and consistent part of the design workflow, but engineers may be less acquainted with open source options, which can offer a cost-effective alternative to commercial applications for enterprises willing to invest the time in what can be a rather steep learning curve.

A variety of well-established open source platforms in the simulation space cover computational fluid dynamics (CFD) and finite element analysis (FEA) along with a contingent of specialty codes for specific industries (such as aeronautics and nuclear reactors) and particular use cases.

In the FEA space, Code_Aster, developed and maintained



SimFlow's intuitive GUI, built on OpenFOAM, aims to deliver a Windows-like CFD experience. *Image courtesy of SimFlow.*



OpenFOAM CFD simulations can investigate the effects of reactor design and operating conditions on the reactor performance and efficiency. *Image courtesy of CFD Direct.*

by the French Department of Energy in the 1980s for engineering nuclear energy facilities in France, and Elmer FEM, open source multiphysics simulation software developed by the CSC-IT Center for Science, are among the best-known entrants.

The CFD category has numerous options with OpenFOAM dominating the landscape, accompanied by SU2, a suite of open source tools written in C++ for CFD and aerodynamic shape optimization.

There are also lesser-known entrants such as Palabos, Fire Dynamics Simulator, a large-eddy simulation code for low-speed flows that emphasizes smoke and heat transport from fires as well as Multiphase Flow with Interphase eXchanges (MFIX).

MFIX is CFD code for modeling reacting multiphase systems developed at the National Energy Technology Laboratory, part of the U.S. Department of Energy and focused on applied research for the clean production and use of domestic energy resources.

Though most open source CAE codes have been around for some time, they tend to appeal to a mostly niche audience, often rooted in academia, or by small pockets of highly specialized experts looking for very targeted solutions. In fact, use of open source CAE is pretty limited, especially at mainstream enterprises, maintains Stewart Bible, managing partner at Resolved Analytics, an engineering services company specializing in CFD as part of product design.

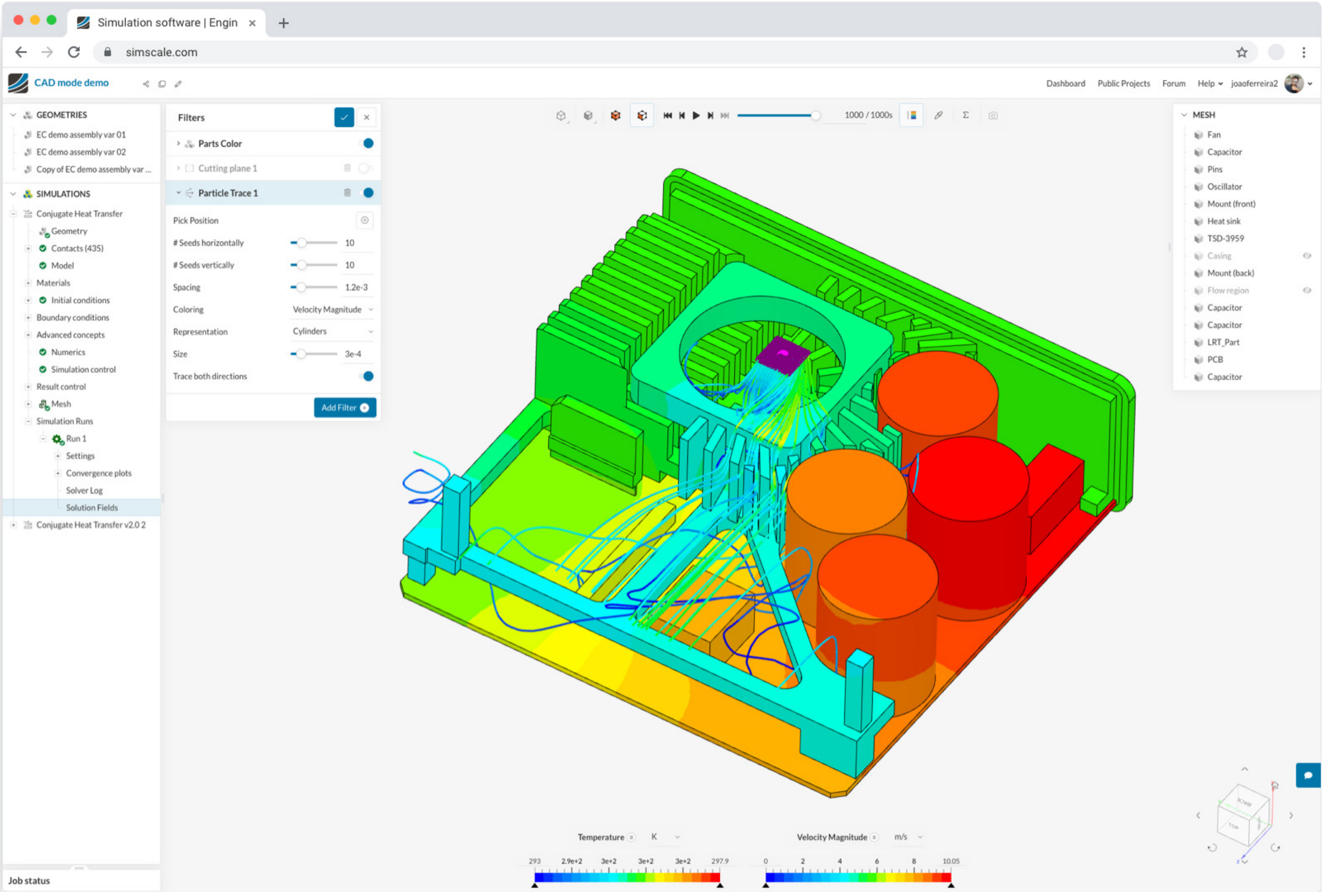
"Our customers are typically not invested enough in CFD to do it themselves," notes Bible. "They'd rather not learn CFD from the ground up or hire a CFD engineer because they don't have enough products to require that kind of investment."

Open Source Simulation: Pros and Cons

Nevertheless, there are tangible advantages to leveraging open source CAE along with a budding ecosystem of vendors offering solutions that build on the core code to make it more user friendly and accessible. Though benefits vary depending on the option, there are some consistent advantages in going the open source route, most notably, significantly reduced costs, transparency of the code and the ability to extend tools with highly specific, customized options.

The biggest draw is economics, given that open source isn't associated with the typically steep licensing fees that accompany most commercial CAE packages. Licensing fees for off-the-shelf CAE tools are usually correlated to the number of processors engaged, which means costs can quickly escalate when bringing out the high-performance computing guns to solve computationally-intensive models and calculations.

"Cost is the biggest driver to go to open source," says Robin Knowles, founder of CFD Engine, a consultancy focused on helping customers with CFD workflows built around OpenFOAM. "If customers see that open source code



Conjugate heat transfer simulation of an electronics cooling application. The simulation is set up in a web browser and runs in parallel in the cloud. Image courtesy of SimScale.

can do what they want it to do as well without the license fee attached, that's the compelling reason to go in that direction."

The flexibility to change code and extend CAE functionality with one's own bespoke capabilities is another reason some favor the open source model. There is also an upside to code transparency—an important benefit when simulation results are critical to driving product performance and safety.

"When the level of science is really challenging, software needs transparency and that's what open source provides," says Chris Greenshields, a director of the OpenFOAM Foundation and the managing director of CFD Direct, the architects of OpenFOAM and a provider of OpenFOAM training and support services. "You have to be able to cast your eyes over the code—if you can't interrogate results, that's a problem."

On the flip side, there's a much steeper learning curve to open source CAE and while there is a large community of engaged users, there isn't a formal support channel, which means users can't count on getting answers to questions in the heat of the moment.

Though there are plenty of trainings and workshops, particularly those keyed to OpenFOAM, often questions on forums can be left unanswered for quite a while, says Dan Combest, manager of North American operations for ENGYS, a company that offers the Helyx CFD platform, which uses the open source OpenFOAM C++ library as the core code base.

"OpenFOAM workshops are fantastic and there are community events where people share ideas, but it can be difficult to get answers to questions," he explains. "You need an answer when you need an answer and that's why some companies shy away from using a complete public project with no official support."

Another hurdle for some engineers is although the open source CAE codes deliver the core solver capabilities, they often lack components for other pieces of the workflow like meshing and visualization capabilities for interpreting results.

"With open source, you often have to run a meshing tool, import results into CFD and export those results to a visualization tool," Bible says. "That broken up workflow costs me time and most can't afford that time."

Time spent navigating a disconnected workflow, not to mention, coming up the learning curve for open source CAE can actually create hidden costs.

"If it takes four weeks of learning for every new problem an engineer encounters, it can easily add up to what you paid for the license," Bible adds. "And what if you invest time in an engineer to learn relatively challenging software and then they leave after a year?"

Greenshields, one of the founders at OpenCFD, which promoted OpenFOAM and was sold to Silicon Graphics in 2011 and eventually taken over by ESI Group, counters the charge that open source opens the door to brain drain. On the contrary, because OpenFOAM is text- and file-based as opposed to a graphical user interface, a record of the CFD workflow and scripts are captured and maintained.

"Someone can come back later and run the script, but if it's stuck in someone's head, the day they walk out the door, your CFD capability walks away," he says.

Finding Middle Ground

Of all the open source CAE programs, OpenFOAM has the most evolved ecosystem, including various third-party offerings built around the core code. Greenshields says the key to a successful open source platform is adhering to a blueprint that recognizes the importance of ongoing maintenance.

"It's all about redesign, repair and publishing, and whoever funds the initiative has to understand this," Greenshields says.

As part of its continuous maintenance, CFD Direct focuses on accessibility, usability, robustness and extensibility.

"We send a message to companies that we need 'no-strings-attached funding' to do the work," Greenshields adds. "Beyond maintenance funding, there are partnerships to add new capabilities to the platform, like the one with a consortium of companies from the process industry aimed at flows with highly complex flow simulations."

Numerous CAE platforms are built on open source libraries that make the tools more comparable to commercial offerings. SimScale, for example, has integrated a remix of OpenFOAM and Code_Aster to offer CFD and general thermomechanical capabilities (with FEA) into its platform. SimScale's mantra is to focus on proprietary CAE, UI/UX and cloud capabilities and enhance it with proven open-source technology.

"By using validated open source technologies, we reduce the time to market of features requested by our users," says Jon Wilde, SimScale's vice president of product. "Then we can focus on the deployment of accessible and collaborative CAE tools on the cloud, which requires specific development skills and investments. Our engineering simulation platform can organically grow to offer, create or customize any solver, and we can develop and scale it as needed."

SimFlow also leverages open source technologies so it can focus on where it can deliver value—in its case, providing a CFD user experience that is comparable to what Windows users are accustomed to. SimFlow's intuitive GUI makes it easier to install the software and create and import meshes, define boundary conditions, even integrate a post-processing workflow using ParaView, a popular open source multiplatform data analysis and visualization application.

"Why reinvent the wheel?" asks Daniel Jasinski, technical director at SimFlow. "Our idea is that experienced CFD users should open the software and start using it out of the box. We are the middle ground—delivering the benefits of a commercial CAE product without the cost." **DE**

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MORE INFO

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- **ENGYS:** ENGYS.com
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Material Insights into Additive Manufacturing

Use of multiscale material modeling and simulation software is helping expand role of additive manufacturing.

BY TOM KEVAN

Additive manufacturing (AM) stands at a crossroads. No longer seen primarily as a prototype-building technology, AM has taken on a role in manufacturing as a key technology enabling on-demand manufacturing. In doing so, however, it has pressed modeling and simulation software developers to take new areas of analysis into mainstream design.

With AM now a prime candidate for fabricating precision and safety-critical components for aerospace and manufacturing applications, it is no longer enough for engineers to know the resulting material properties after the AM process. Increasingly, they also need insights into how the properties came about and how they impact the performance of the printed part.

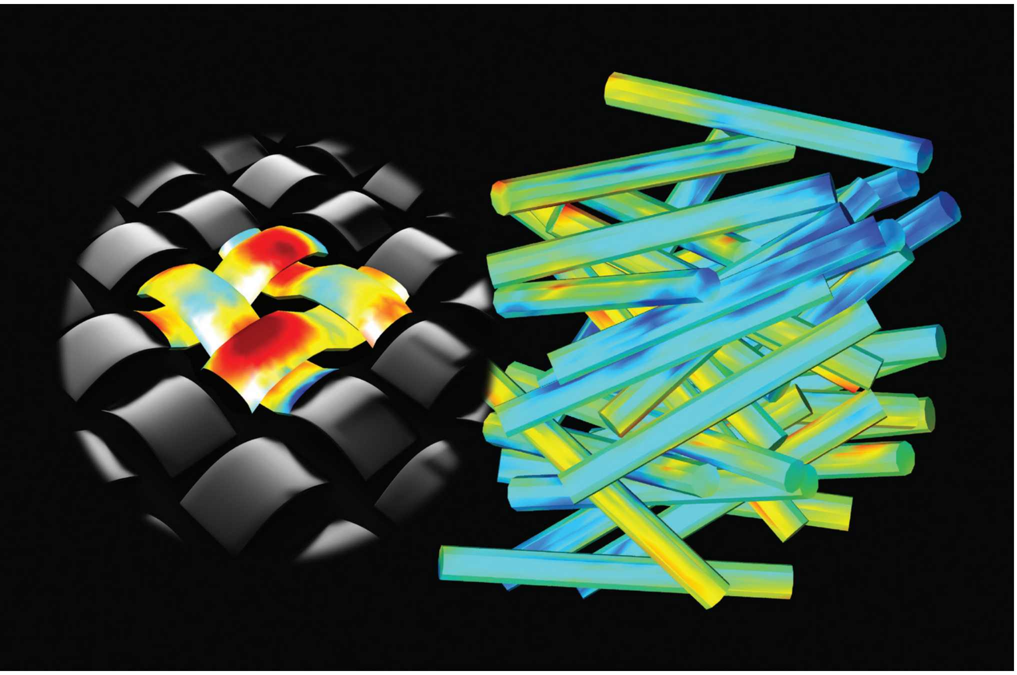

Fig. 1: Multiscale material modeling and simulation tools aim to provide insights into the interactions of microstructural features and the AM materials and processes that are involved. Microstructures can take on forms such as a weave (left) or short fibers oriented in random directions (right). *Image courtesy of Siemens Digital Industries Software.*

To address this need, engineering software developers are offering a technology called multiscale material modeling and simulation software. These platforms aim to provide greater understanding of the connections between materials, 3D printing processes and part performance.

Now, the question is to what extent can these software platforms enhance AM design and fabrication, and in what areas must the software grow to maintain additive technology's expanding role in manufacturing?

Design-Material-Process Connection

To understand what multiscale material modeling and simulation can and cannot do, engineers must recognize the interdependencies of a print job's design, material and fabrication processes. Ultimately, the quality and performance of the printed part is determined by the properties and interactions of these

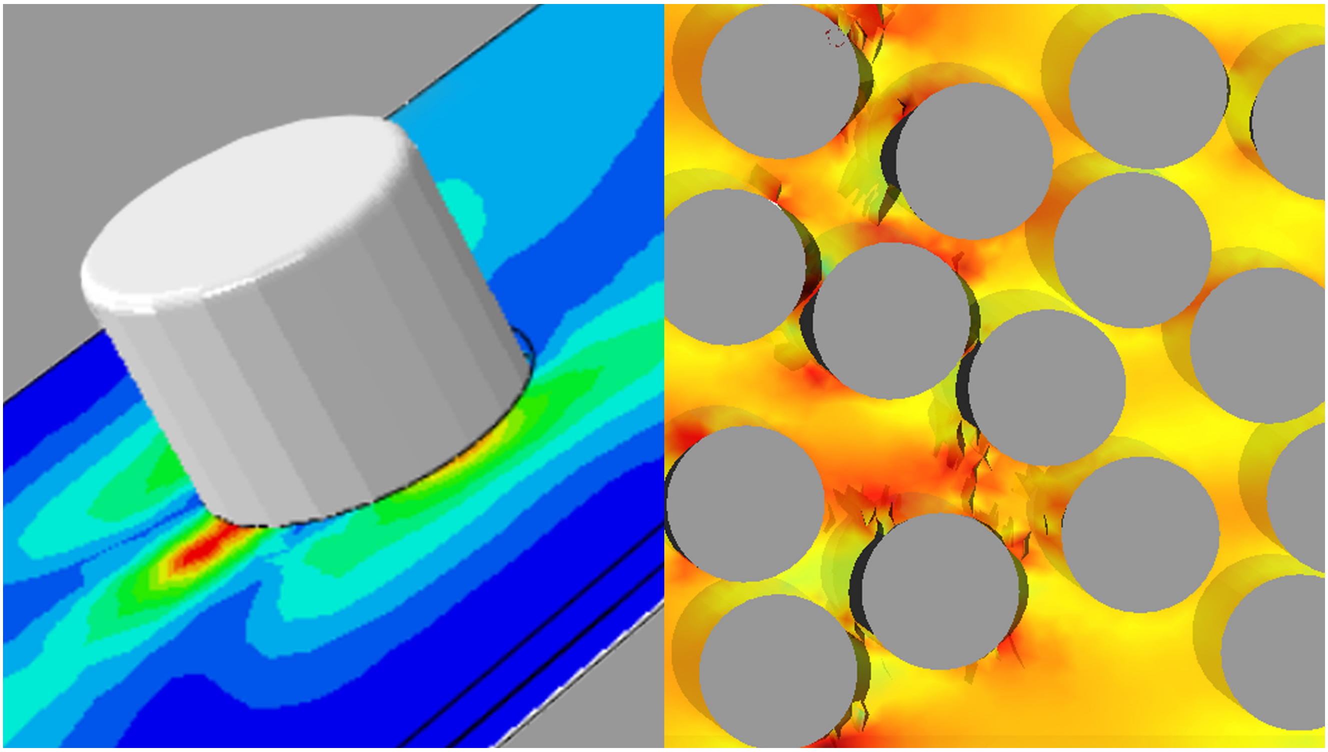

Fig. 2: The right panel shows cracks in a microstructure. The left panel shows structural performance of a part made from this material. The software enables the engineer to zoom into the material microstructure to identify the cause of failure, see how damage mechanisms affect structural performance and optimize for performance. *Image courtesy of Siemens Digital Industries Software.*

three elements. The complexities of these relationships are amplified by what sometimes seems to be an infinite number of variables.

"One can take the same geometry, use the same additive manufacturing machine, with the same settings, and still obtain different material properties on the component just by orienting the component differently or using different supporting structures," says Hunor Etele Erdélyi, research engineer, senior manager at Siemens Digital Industries Software. "These will implicitly impact the local temperature histories, potentially leading to different local microstructures and defects (Fig. 1)."

Thus, it's critical to consider the design, printing process and material properties together to accurately assess the performance of the 3D-printed component. Omitting any of the elements or properties invariably leads to unsatisfactory results. This is particularly true at the design level.

"If the models do not account for nonlinear properties—such as temperature and process-dependent material properties—they cannot produce a design that delivers superior quality and performance," says Ehsan Toyserkani, director of the Multi-Scale Additive Manufacturing Laboratory at the University of Waterloo in Ontario, Canada.

Informed Decision-Making

Once this process-property-performance link is established, however, engineers can see the effects that design and manufacturing decisions on material properties and the component's performance. This enables engineers to search for design alternatives—using technologies such as generative design and topology optimization—to use source material more effectively while optimizing designs and fabrication parameters. In addition, when the properties of a material are accurately known, that knowledge enables the most efficient use of that material to create a safe part.

An industry case study that involves Stratasys demonstrates this idea. "Multiscale material modeling and simulation enabled Stratasys to iterate designs and parameters using simulation instead of devoting time and materials to testing via printing," says Olivier Lietaer, additive manufacturing business development engineer at Hexagon. "It also used simulation to anticipate printing problems by evaluating the impact of printing direction and location, and to explore the effects of process parameters on process quality and part fidelity."

In this case, the engineers found a correlation when comparing results of warpage simulation with 3D scan measurements of the printed composite tool. As a result of material modeling, advanced simulation capabilities helped the company reduce warpage from 0.5 mm to less than 0.1 mm, or by about 20%, according to Lietaer.

Multifaceted Analysis Required

To achieve results like those in the Stratasys use case, it is important to consider that additive processes shape mesoscale and microscale material microstructures. These structures

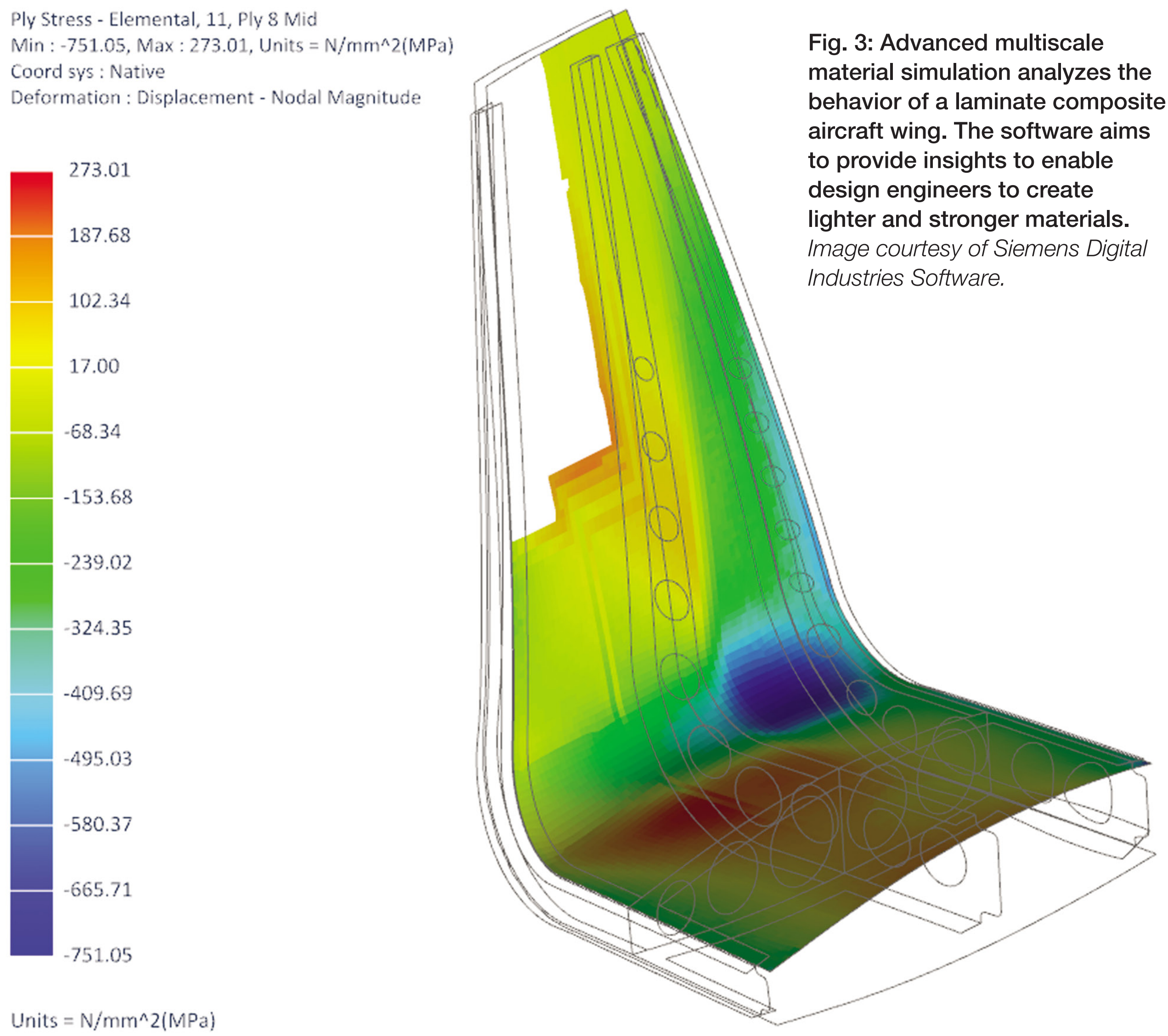

Fig. 3: Advanced multiscale material simulation analyzes the behavior of a laminate composite aircraft wing. The software aims to provide insights to enable design engineers to create lighter and stronger materials. *Image courtesy of Siemens Digital Industries Software.*

dictate the effectiveness of material behavior at the part, or macroscale, level (Fig. 2).

Advanced modeling and simulation tools must factor in multiple microstructural features and the AM materials and processes that create them. For instance, homogeneous materials, such as polymers or metals, exhibit anisotropy during additive processes, often assuming material properties like stiffness and strength in the direction that the 3D-printed layers are stacked. Thermal processes affect the succession of layers that comprise a 3D-printed part. These processes can drive microstructural changes in metals and define interlayer-adhesion quality in polymers.

An example of interlayer-adhesion effects is seen with polyether ether ketone (PEEK) and poly ether ketone ketone (PEKK), which are semi-crystalline materials that offer ideal temperature resistance and fatigue properties. The catch is that these properties can be achieved only if the materials are fully crystallized. Simulation can predict material properties—such as the degree of crystallinity of the interlayer adhesion in function of the material and process setup—and help engineers optimize material and design performance. Inadequate processes can cause an agglomeration of partially molten particles on part surfaces, which can result in rough finishes and diminished fatigue performance.

The link between material and process is even stronger for composites, and especially with material extrusion systems. In these cases, the printer-head deposition strategy, or toolpath, drives fiber orientation, which is largely responsible for the part's mechanical behavior (Fig. 3).

Engineers can use these types of insights to predict AM build-parameter effects on key part characteristics, such as residual stress, surface roughness and resulting microstructure.

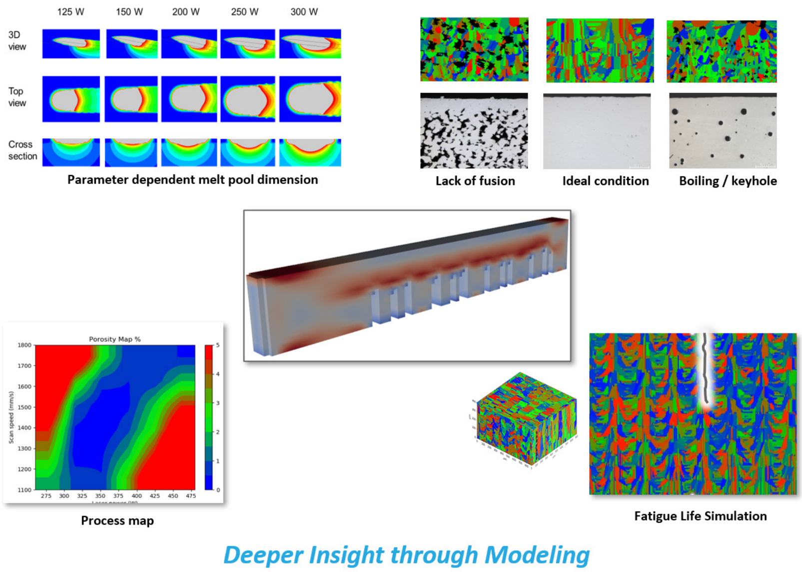

Fig. 4: Here is a graphical depiction of (upper left) melt pool geometry of AM parameter settings; (upper right) microstructure modeling of AM process impact on material quality; (center) a component model of projected locations of elevated residual stress; (lower right) a representative volume element and fatigue life simulation of AM material; and (lower left) a process map of scan speed and laser power impact on AM material porosity. *Image courtesy of Sentient Science.*

"AM build parameters—such as laser intensity, laser speed, hatching space, powder-layer thickness and orientation of build—can be considered as part of the process modeling of the more advanced solutions," says Jingfu Liu, chief scientist for additive manufacturing at Sentient Science. "These predictive modeling tools usually agree quite well with experimental results for both microstructure and performance across multiple geometries, AM materials and loading conditions (Fig. 4)."

Application Considerations

Another element that influences material models and simulations is the 3D-printed component's build case.

Take for example a fatigue-critical metal component produced by laser powder bed fusion (LPBF). Here, the fatigue is driven by the component's geometry, applied loads and local material properties, including process-induced fatigue-influencing factors like surface roughness and defects. In this case, surface roughness will most likely have the greatest impact, followed by the sub-surface defects (e.g., pores, cracks and inclusions), and the material microstructure.

To make modeling these cases even more difficult, fatigue-influencing material properties are typically local properties, which change from one region of the component to another. In these cases, the calculations must also treat the material properties in a local manner.

"Using simulation technology that can relate the different local fatigue-influencing factors induced by the additive manufacturing process to the fatigue performance of the component enables the engineer to concurrently analyze the impact of the design and the manufacturing itself on the fatigue of the component," says Erdélyi. "It can turn out that just by reorienting the component within the build can produce favorable local properties in a fatigue hot spot that will subsequently lead to improved fatigue life."

Challenges and Shortcomings

Multiscale material modeling and simulation software elicits a lot of excitement, and holds benefits for design and manufacturing engineers. A balanced evaluation of the current capabilities of this nascent technology, however, spotlights challenges that evoke a more guarded response. Many of the concerns arise from the fact that AM is still in the relatively early stages of its development.

"The maturity of additive manufacturing technology is a notable challenge to predicting anisotropic behavior, especially considering that material performance is often dependent upon the characteristics of printers," says Lietaer. "Defects such as material porosity and residual powder are variables that can't be predicted by even the most advanced simulation. Complex thermal processes that influence material properties, such as material microstructure, metallurgical characteristics, interlayer adhesion, and crystallinity, make anisotropy challenging to predict simply by virtue of their inherent intricacy."

Not all shortcomings, however, take the form of technology constraints. Some are associated with the practicality of the technology.

"It is possible to link processing parameters and materials to microstructure," says Brent Stucker, distinguished engineer at Ansys. "But it is currently inefficient and time-consuming to try to predict those microstructures everywhere in a part simultaneously. As such, there is still a disconnect between the ability to predict microstructural aspects of a part and their effects when scaled up to an entire part."

Part of this challenge stems from the sheer scale of the required analysis, which spans different time and length scales.

"A component produced by LPBF has a typical size of 20 to 30 centimeters and can have kilometers of laser weld tracks, produced over many hours, while the melting and solidification of the metal happens at a scale of approximately 100 micrometers in a fraction of a second," says Erdélyi.

Another challenge stems from the fact that these are multiphysics applications that require a diversity of simulation methods to be able to link the material process to the resulting material properties and their impact on part scale performance. In addition, some of the different tools and methods used in these applications have yet to be integrated in a streamlined end-to-end simulation platform that enables efficient use and to manage the different models.

Compounding the complexity issue is the fact that these applications can require significant computational resources.

"Design tool developers and users make trade-offs about how a tool will accurately represent the design data and the anisotropic behavior of the material," says Seth Hindman, senior manager, Product Strategy and Management, of Autodesk. "Anisotropy introduced by mixed materials or spatial variation can be intense to calculate by explicit modeling kernels. Conversely, implicit representations of models that enable real-time modeling performance are difficult for analysis and manufacturing tools to directly leverage."

Some software providers, however, aim to overcome these hurdles by connecting their design and engineering tools to the cloud, offloading intense calculations and opening the door for engineers to explore variations.

That said, these computational resources can come with a hefty price tag, particularly when the engineer seeks rapid, high-fidelity part qualification via modeling.

"The expensive computational cost to model the layer buildup process limits the practical applications of most predictive approaches," says Behrooz Jalalahmadi, vice president of additive manufacturing and life prediction technologies at Sentient Science. "The AM industry requires efficient computational approaches that can be performed in an affordable computational manner—in terms of both cost and time."

A Place in the Thread?

No discussion of a software platform's strengths and weaknesses is complete until it addresses how well the program fits into the digital thread. In the case of multiscale material modeling and simulation platforms, the answer to this question is essentially an extension of challenges around complexity.

The reality is that it will not be easy to integrate all the required simulation tools into one digital thread because of the multiscale, multiphysics and multi-attribute aspects. To meet this challenge, software providers will have to increase the breadth and depth of their offerings.

"The challenge is to expand and enhance the scope of material definition within the digital thread," says Hindman. "For example, the majority of toolsets expect the answer for a material and its associated material properties to be discrete. Going forward, these systems will need to be able to tackle the answer to this question based on numerous variables and defined criteria."

These modeling and simulation platforms are certainly works in progress, and their growth and enhancement are closely linked to general AM technology. The software providers, however, still must improve their platforms' interoperability and connectivity if they plan to be a contributing part of digital thread.

"Additive manufacturing has long moved past the state of being just for prototyping in many industries, so the imperative is to connect workflows and the digital thread in an actionable way to the shop floor so that test, metrology and serial production data can be used to validate, correct and improve design choices and manufacturing processes," says Toyserkani. DE

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MORE INFO

- **Ansys:** Ansys.com
- **Hexagon:** Hexagon.com
- **Sentient Science:** SentientScience.com
- **Siemens Digital Industries Software:** SW.Siemens.com/en-US
- **University of Waterloo:** UWaterloo.ca

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Accelerated Generative Design

Emerging applications in the generative design and additive manufacturing space embrace more powerful compute resources

Generative design tools and techniques have emerged over the past several years, touted as a way to more efficiently explore the design space and help engineers find the right solutions to their design problems, faster and more creatively. However, takeup of generative design (GD) approaches has lagged industry hype.

In the most recent Digital Engineering Technology Outlook survey (December 2020), only 15% of respondents reported currently using generative technology, and just 26% indicated that GD factored into their future plans. And only 12% of respondents claimed to be very familiar with the concept.

Adoption of generative design has been hampered by this lack of understanding, and by marketing messages that have tied the use of this approach to (often more costly) additive manufacturing processes. However, thanks to a combination of the increased use of simulation in the design cycle, and the availability of more powerful workstations that allow that simulation to take place in the background, generative design can be applied to a much wider range of design problems.

Emerging Use Cases

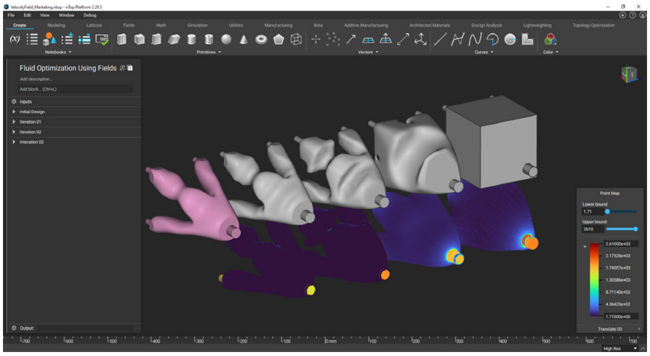
According to the ASSESS Initiative, generative design uses algorithmic methods to create feasible designs or outcomes from a set of performance objectives, performance constraints, and design space for specific use cases.

While initial offerings tend to couple topology optimization with additive manufacturing, the real value of generative is not limited to that approach.

Right now, Autodesk Fusion 360 and Altair solidThinking have led the way in terms of mainstream CAD companies with generative offerings, along with PTC via its acquisition of Frustum. But there are a number of newer companies with generative design tools that have a lot to offer in terms of functionality for specific tasks and markets.

And there is a case to be made that generative, in order to be truly effective and attain widespread adoption, needs to move beyond the topology optimization functions that are the most widely understood.

"Generative design is way bigger than what's now mostly understood as it being a design tool for additive manufacturing," says Dr. Thomas Reiher, director of generative design for MSC Apex, at MSC Software. "Both produce these organic shapes so it's a perfect way of working together. But the real promise is bringing the power of computing and the knowledge of multiple systems (like different physics and manufacturing methods) into an automated way to get to a final design solution."



By coupling design and simulation together using Field Driven Design, nTopology enables the power of implicit geometry to be unlocked in ways that were not previously possible. *Image courtesy of nTopology*

Jacobs Engineering, a contractor on NASA's Exploration Portable Life Support System (xPLSS), leveraged Creo Generative Design to come up with optimized and lightweighted designs for brackets, housings, and faceplates, and to rapidly explore hundreds of combinations of different materials and manufacturing processes. Using Creo 7's Generative Design functions, the team was able to explore a full suite of manufacturing methods and apply whichever one was best suited to any given part, notes Russell Ralston, xPLSS design manager at NASA's Johnson Space Center.

Beyond Topology Optimization

Relative newcomers in the market like nTopology and others have emphasized that the value of generative design lies in optimizing for the most critical performance factors beyond topology or structural optimization. That can include part/component reduction, thermal optimization, etc.

nTopology provides a platform that helps engineers create and define their own generative processes for creating new designs. The nTopology platform accomplishes this through capabilities like implicit modeling (which allows users to generate a design regardless of complexity), field-driven design, and reusable workflows.

For the full version of this article and more information about the Advanced Product Development Resource Center, visit APDRC.com.

Edge Computing as Antidote to Remote Engineering Challenges

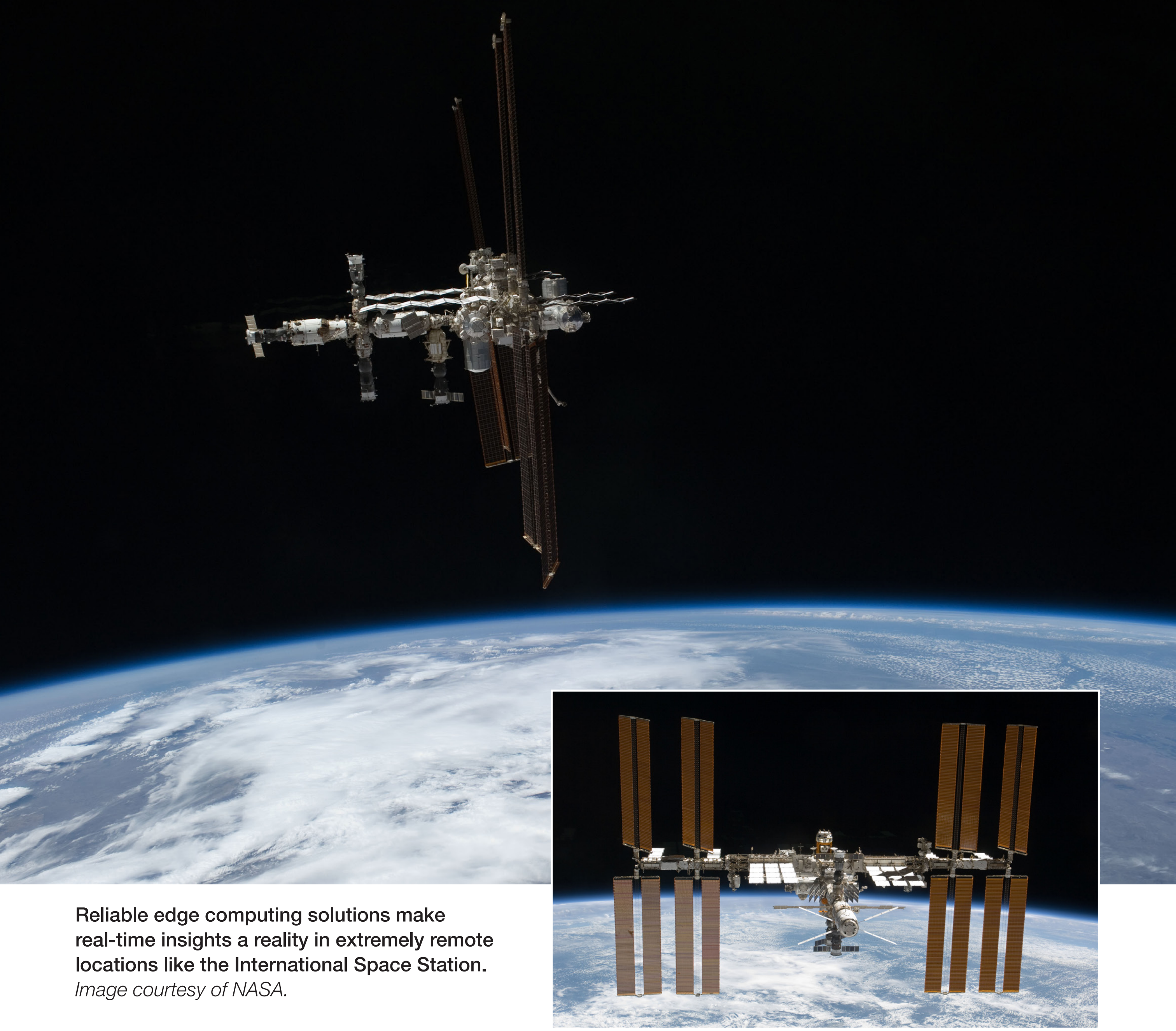
Cloud and edge, when used in combination, yield a novel, cost-efficient IoT deployment solution for smart products.

BY RANDALL S. NEWTON

Of all the accolades given to the Mars Perseverance Rover, add one more: most distant successful deployment of edge computing.

Edge computing is defined as a distributed computing ecosystem that brings computation and data storage closer to the collection location. In the case of the Mars exploration, closer means millions of miles, improving on signal latency measured in minutes instead of milliseconds.

The Mars Perseverance Rover shows just how far edge computing can take us. *Image courtesy of NASA.*



Reliable edge computing solutions make real-time insights a reality in extremely remote locations like the International Space Station. *Image courtesy of NASA.*

Edge computing offers local computation, making for faster decisions. Cloud computing offers fast computation of large data sets, and the ability to run complex artificial intelligence and machine learning algorithms. Working together, cloud and edge computing offer a new and cost-effective IoT deployment solution for smart products.

NASA's Perseverance and its sidekick drone helicopter Ingenuity have to operate without direct control from Earth. Most of the data analysis is done on site, using a PowerPC 750, the CPU best known as the processor in the 1998 iMac. All data is transmitted back to Earth, but the 12-minute sending time one way makes direct control impossible.

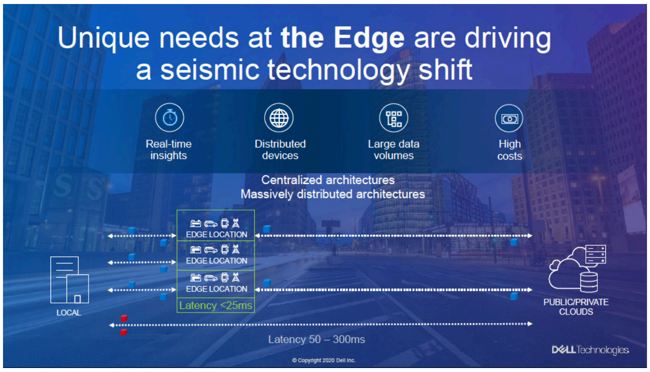
Even before going to work exploring Mars, data was gathered from Perseverance's descent from an array of sensors in the heat shielding. Sent back to Earth after landing, this data allows NASA engineers to upgrade heat shields and other essential landing equipment based on experience and not just simulation.

International Space Station on Edge

The edge computing environment on Mars is not the first extraterrestrial deployment of its kind. Hewlett-Packard Enterprise (HPE) and NASA are testing a new computer to run artificial intelligence routines on the International Space Station. "Spaceborne Computer-2" will allow astronauts to process data locally, in minutes instead of months as with previous low-power computing resources on board.

"The most important benefit to delivering reliable in-space computing is making real-time insights a reality," Dr. Mark Fernandez, HPE's principal investigator for Spaceborne Computer-2, recently told news site FedScoop (bit.ly/2QQhSls). "Space explorers can now transform how they conduct research based on readily available data and improve decision-making."

Such local-and-remote computing working in tandem is growing rapidly for more down-to-earth applications. En-



Edge computing offers local computation, making for faster decisions. Cloud computing offers fast computation of large data sets, and the ability to run complex artificial intelligence and machine learning algorithms. *Image courtesy of Dell Technologies.*

gineering organizations are finding benefit in shifting from datacenter and workstation-centric operations to embracing remote collaboration, using computing resources on site and in the cloud.

Computational Immediacy

"Edge computing gives immediacy," notes Nick Brackney, senior consultant for cloud at Dell Technologies. "Workflows that get pushed to the Edge have volatile data; its use is required immediately."

Such immediacy is essential to gain consistency across the dispersed ecosystem. Applications can be operating at the remote site, making real-time decisions based on previous and ongoing deep learning neural networks that operate in the cloud.

"Real-time operations at the Edge; training and optimization at the cloud," notes Brackney. "It is a virtuous cycle for autonomous applications."

New technologies such as autonomous vehicles generate terabytes of data per day. To process all that data is a challenge no matter its location. 5G improves the latency issues, but there is still too much data in the device to make real-time operational decisions remotely.

"The challenge [for engineering] is to balance how much to send to the cloud and how much to process at the edge," notes Brackney. "Each workload is different."

Data Gravity

At a macro level, this trend of dividing data processing between a central and a remote location is an example of what experts call "data gravity." The new generation of computationally intensive products is the gravitational force drawing applications, services and other data just as a planet draws everything toward its center.

"The theory is that data acts like gravity," notes Matt Trifiro, CMO of Vapor IO, a company working on what they call the Kinetic Edge, described as a wide-scale network for solving edge computing issues.

"A petabyte takes a month to send on today's internet," says Trifiro. Data gravity is when the application to process this data is sent to where the petabyte of data resides. "There is no one edge," notes Trifiro. "You must be able to access the edge everywhere as one common set of infrastructure, [one in which] companies bring their technology to the common infrastructure."

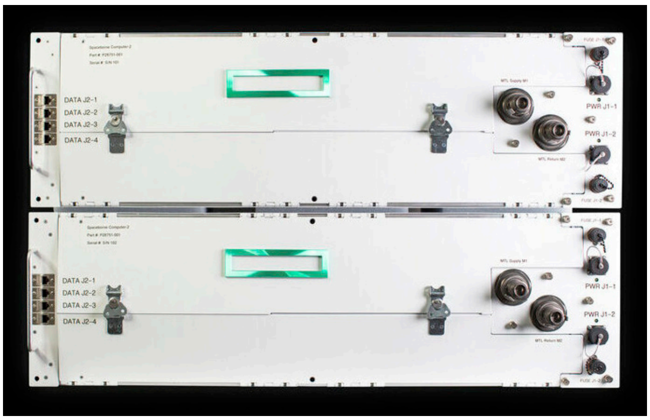
On a practical level, data gravity can become a source of ongoing contention between the information technology (IT) and the operational technology (OT) teams.

"These are all snowflake deployments; every use case is different," notes Dell's Brackney. "IT has its issues. The OT people who own the factory are more device oriented. To succeed at the Edge, IT and OT must come together and digitize all their workflows. This is the chasm to cross."

Containers and Kubernetes

Two newer data technologies coming to the fore with the rise of edge devices are containers and Kubernetes. Containers are like virtual machines, but lighter in size and defined for a narrow set of capabilities. A container has its own file system and its own share of a local CPU. It is decoupled from its underlying infrastructure, allowing it to be portable across cloud and OS distributions.

Containers offer Agile application and deployment, crucial in creating IoT-enabled products. Containers decouple development from operational issues, and use the ability to create an application image when required, rather than at initial product deployment. Containers are loosely coupled in operation, and allow users to easily deploy distributed and



Spaceborne Computer-2 will allow astronauts to process data locally, in minutes instead of months as with previous low-power computing resources on board. *Image courtesy of HP.*

elastic services. There is no monolithic OS stack as in the typical workstation or server.

Kubernetes is a portable, extensible open source platform for container orchestration and management. The Kubernetes platform facilitates declarative configuration and device automation. Google did the original research and now oversees work from the growing, robust Kubernetes open source community.

Kubernetes provides a way to run containers as elements in a distributed network. The Kubernetes platform takes care of deployment, service discovery, load balancing and storage orchestration. If a container fails, the Kubernetes platform can replace or isolate it. However, Kubernetes is not a complete Platform-as-a-Service offering. Instead, it is more like a sack of IT pieces for building and deploying independent operations.

Edge and the Developing World

The ideas behind edge computing and its relationship to cloud computing may seem fairly straightforward in countries with an established internet infrastructure. In countries with limited infrastructure, the national telecommunications companies (telcos) are the data providers.

"Add 5G and you have a natural last-mile answer to end users," notes Michael DeNeffe, director of product development for Cloud at AMD.

As a vendor heavily invested in graphics, AMD sees edge computing as a great way to enable graphics intensive workflows that use virtual reality or augmented reality (AR/VR) in a more location-independent fashion.

"VR/AR in engineering workflows are awesome, but unless you are directly connected to the cloud at high bandwidth it gets dicey," according to DeNeffe. The solution, DeNeffe says, is fast edge networks using 5G.

"Telcos are trying to figure out how to monetize this," DeNeffe notes. "They are looking at workloads in various applications, including high-performance engineering. Companies can now hire engineers in time zones all over the world. [With edge computing] they can share data sets and take advantage of local capabilities. There is no need for centralized work."

Edge and the Cost of Engineering

Companies have two factors in consideration regarding engineering talent, DeNeffe says: head count and cost to deploy engineers.

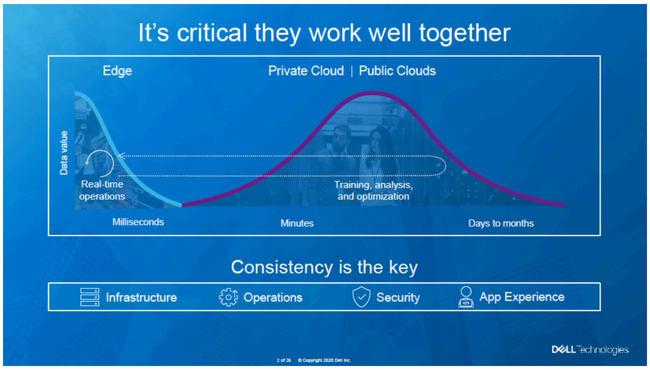
"Rather than a team of ten engineer[s] in California designing a product, hire 40 engineers globally collaborating over edge networks," says DeNeffe, who adds this has a fundamental quality of "quicker time to money and more efficiency. Network availability means hiring engineers anywhere."

How should engineering teams evaluate their edge computing needs? DeNeffe says they need to focus on the problem to solve.

"Edge brings you closer to the actual compute," DeNeffe says. "It is a honeycomb of aspects that makes edge [computing] exciting. If you provide capability on networking or hardware, you always find people taking advantage of it for software or engineering workflows."

Fast networking is opening use cases previously thought to be impractical, such as using VR/AR technology in remote worksites.

"When virtual reality first came out, we realized you needed a direct connection to a computer or an extremely fast network," says DeNeffe. "Use cases broke down. But now they are picking up again thanks to fast networking." DE



Local-and-remote computing working in tandem is a more common scenario, as engineering organizations see the benefits in shifting from datacenter and workstation-centric operations to embracing remote collaboration. *Image courtesy of Dell Technologies.*

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MORE INFO

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- **Dell Technologies:** DellTechnologies.com
- **HP Enterprise:** HPE.com/us/en/home.html
- **Vapor IO:** Vapor.IO

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Why **Digital Twins** Need to Call the Cloud Home

The cloud connects real-world data to digital replica.

BY KENNETH WONG

If you were a manufacturer assembling a digital twin, what might be the basic components in the kit? This was the hypothetical question that brought together Leo Kilfoy, vice president of smart factory platform, Hexagon; Peter Lyu, vice president of global solutions, Rescale; and S. Ravi Shankar, director of simulation, Siemens Digital Industries Software. The conversation took place as an episode of DE Hot Seat webcast, originally broadcast on March 25, 2021, sponsored by Hexagon, Rescale and Siemens.

"A digital twin is a replica of an object, such as a product, system, or machine. Large-scale digital twins can include factories, hospitals, and cities," Kilfoy explained. "The twin can take real-world data as input and produce predictions based on simulation and analytics."

Shankar added that the digital twin needs "bidirectional connectivity between the physical asset and the virtual representation. Real-world product performance data can used for simulation; simulation can be used to improve the performance."

Metrology to Produce Faithful Twins

With this working definition, panelists agreed a digital twin is much more than a detailed 3D model, usually created in CAD software. While a detailed CAD model is sufficient for manufacturing, it does not reflect the real-world conditions (such as the temperature, vibration, and use) of the operating object in the field. Therefore, a CAD model is severely limited as an entity for predictive study and analysis.

Lyu said he had just started his career in aerospace engineering when the digital twin concept first emerged. The digital twin phenomenon was "partly fueled by the increase performance of simulation, and partly by the adoption of cloud and IoT devices at an industrial scale," he noted.

Cloud infrastructure, Lyu pointed out, is essential to the setup and maintenance of digital twins as it's the most affordable network technology to facilitate ongoing bidirectional communication between equipment in the field and the digital replica.

Kilfoy believes metrology is also a critical component of the digital twin setup. The high-definition 3D scans of the parts and products as manufactured more accurately reflect the object before deployment. They include, for instance, heat-induced deformation to the part that occurred during manufacturing. Therefore, a digital replica constructed from such scans constitutes a superior digital twin than a CAD model.

"Remember: there can be multiple models associated with the digital twin," said Shankar. "One for thermal performance, one for structural performance, one for electromagnetics and so on. The key is, the digital twin needs to continuously evolve for different departments."

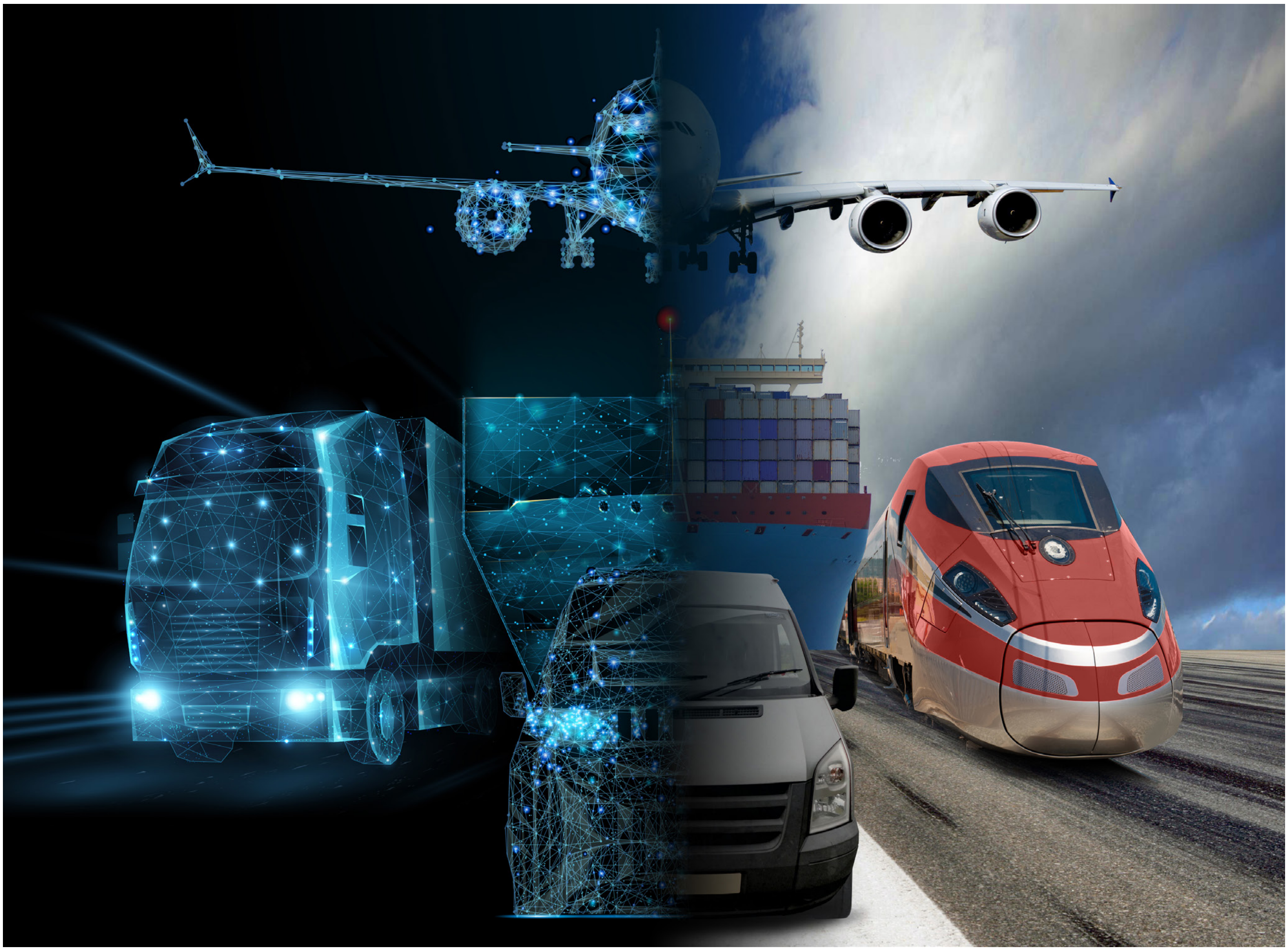
The Invisible Cloud Bridge

The obstacle many manufacturers face with their digital twin initiatives is not the digital model but "the deployment of the underlying infrastructure to support the solution, such as the network technologies to stream the real-world data from the IoT device to the central hub, or the [high-performance computing] resources needed to simulate the virtual model," said Lyu.

This was the reason that, historically, only large enterprises were able to launch and maintain digital twins. But this may be changing, with more affordable on-demand cloud service providers now available.

The input required to simulate the digital twin's behaviors varies based on the characteristics of the product, according to Kilfoy.

"Consider the digital twin of a fleet of vehicles, as opposed to a living, breathing, evolving factory," he said.



"They have different challenges in traceability."

For industrial machinery digital twins, recording equipment vibration, rotation and wear and tear is important. For factory digital twins, capturing the daily processes, operations and equipment up times and down times are prioritized.

Customizing Twins

Leading public cloud providers are beginning to offer digital twin-related products, Lyu pointed out. Microsoft, for example, offers Azure Digital Twins, described as "an [IoT] platform that enables you to create a digital representation of real-world things, places, business processes, and people."

"Every digital twin is different so it's quite a challenge to implement. Each is highly customized, requires special skills and knowledge. That's the gap that we feel we can fill," said Lyu.

Rescale counts MSC Software—part of Hexagon—and Siemens as its partners. These simulation software programs are preloaded in Rescale's cloud infrastructure. Therefore, Lyu feels Rescale is well-positioned to offer turnkey digital twin solutions.

Because different countries have different regulations for cloud deployment, Rescale has set up different data centers in different regions to comply with the requirements. This, too, helps eliminate a barrier for digital twin implementation.

"Rescale has gone through the certification process, so our customers don't need to worry," Lyu said.

Predictive models are the outcome of combining physics-based models and real-world data, according to Shankar. With massive real-time data available on certain field devices (for example, hourly temperature readings), it may be wise to employ machine-learning algorithms, such as reduced-order modeling, to keep the input manageable, Lyu recommended.

This Hot Seat episode is available for on-demand viewing. For the link, visit archived episodes at digitalengineering247.com/topic/category/webcasts, or visit the registration page. **DE**

Kenneth Wong *is DE's resident blogger and senior editor. Email him at de-editors@digitaleng.news or share your thoughts on this article at digitaleng.news/facebook.*

MORE INFO

- **MSC Software / Hexagon:** Hexagon.com
- **Rescale:** Rescale.com
- **Siemens:** SW.Siemens.com

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3D Printing Down Under

Australian race team says additive manufacturing is addictive.

BY KIP HANSON

“When you have a 3D printer, the world is your oyster.” That aphorism is attributed to Bruce Stewart, team principal for Walkinshaw Andretti United (WAU), a supercar race team based in Melbourne, Australia.

Since purchasing a Stratasys F120 fused deposition modeling (FDM) 3D printer from area distributor TCL Hofmann in March of this year, he and his team have been busy kicking the tires on their new equipment. They’re starting to wonder how they ever raced without it.

“Rapid prototyping has become an important factor in building better race cars,” Bruce Stewart, team principal for Walkinshaw Andretti United, says.

“Rapid prototyping has become an important factor in building better race cars,” says Stewart. “As with anyone in motorsports, our engineers fight for tenths of a second. They might achieve these small wins with more effective hand tools in the pit area, ergonomic adjustments that make the driver safer and more comfortable, or modifications to the race car itself. With 3D printing, you can quickly conceptualize and test such ideas. It’s become an addictive improvement tool for us.”

Making Fast Parts Quickly

WAU was born in 2017 as the result of a partnership between three leaders in the world of racing: Walkinshaw Racing’s Tom Walkinshaw, American racer Michael Andretti and McLaren Formula One CEO Zak Brown. Together, with drivers such as Queensland native Chaz Mostert and Bryce Fullwood of Darwin, their goal is to dominate Australia’s Supercars Championship.

Walkinshaw Andretti United has been busy using its Stratasys 3D printer to manufacture steering wheel housings, camera mounts, air brake ducting and parts for the pit crew. *All photos courtesy of WAU.*

It looks like 2021 will be their year to accomplish just that. Currently ranked second, the WAU team is "on a journey back to the top," says Stewart. "Everything we do here is about winning. Our three owners are out-and-out racers, so my crew and I have been tasked with utilizing every available resource to not only make our cars go faster, but increase the team's operational performance as well. The Stratasys 3D printer is an avenue for us to further enhance our innovation and develop additional opportunities. It eliminates design limitations and allows the engineers to contemplate novel ways to generate speed."

WAU's innovations include 3D-printed steering wheel housings, camera mounts, air brake ducting, buttons and brackets for pit tools, and any sort of component to make life behind the wheel easier. Stewart notes that this last part—ergonomics and comfort—is vital.

"That's key, because the second or two that a driver loses trying to find a lever or adjust a knob might be the second that loses the race," he says.

Chaz "Mozzie" Mostert drives Car 25 for Australian race team Walkinshaw Andretti United. His personal vehicle is a Chevrolet Silverado 1500 pickup truck.

Switching Sides

This isn't the team's first experience with additive manufacturing. Stewart explained that the Walkinshaw Automotive Group—WAU's sister company—is the largest automotive manufacturer in Australia. They also own a pair of Stratasys 3D printers, and produced prototypes for WAU before the racing team invested in their own equipment. Somewhat surprisingly, Walkinshaw has built a substantial business out of making American vehicles suitable for Australia's roadways.

"The change from a left-hand to right-hand drive is so extensive that we don't use the word conversion," says Stewart. "It's more of a complete remanufacturing. A Chevrolet Silverado, for example, requires nearly 700 unique parts and goes all the way down to the wiring harness level. It's a huge business for us. We've done Volkswagen Amaroks, Camaros, RAM pickup trucks—we'll probably remanufacture 10,000 vehicles this year."

Walkinshaw Andretti United has been busy using its Stratasys 3D printer to manufacture steering wheel housings, camera mounts, air brake ducting and parts for the pit crew. *All photos courtesy of WAU.*

It looks like 2021 will be their year to accomplish just that. Currently ranked second, the WAU team is "on a journey back to the top," says Stewart. "Everything we do here is about winning. Our three owners are out-and-out racers, so my crew and I have been tasked with utilizing every available resource to not only make our cars go faster, but increase the team's operational performance as well. The Stratasys 3D printer is an avenue for us to further enhance our innovation and develop additional opportunities. It eliminates design limitations and allows the engineers to contemplate novel ways to generate speed."

WAU's innovations include 3D-printed steering wheel housings, camera mounts, air brake ducting, buttons and brackets for pit tools, and any sort of component to make life behind the wheel easier. Stewart notes that this last part—ergonomics and comfort—is vital.

"That's key, because the second or two that a driver loses trying to find a lever or adjust a knob might be the second that loses the race," he says.

Chaz "Mozzie" Mostert drives Car 25 for Australian race team Walkinshaw Andretti United. His personal vehicle is a Chevrolet Silverado 1500 pickup truck.

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What's New in AutoCAD 2022?

AutoCAD promises a more connected experience across platforms.

BY DAVID COHN

Once again, March marks the annual release of new versions of AutoCAD and AutoCAD LT. AutoCAD 2022, the 36th iteration of the company's flagship CAD software, includes just a handful of new features, many of which only work in conjunction with the company's growing collection of online tools, such as the AutoCAD web and mobile app and BIM 360.

Within AutoCAD and AutoCAD LT, a new tool automates the object counting in a drawing. You can pull a drawing out of the AutoCAD window and float it onto a second monitor. Plus, there are new tools for drawing review and markup, sharing a controlled copy of a drawing and pushing PDF versions of drawing sheets to an Autodesk online storage location.

As has been true since the 2019 release, AutoCAD 2022 users also have access to seven specialized toolsets: Architecture, Electrical, Map 3D, Mechanical, MEP, Plant 3D and Raster Design. But, other than the enhancements to AutoCAD itself, these also have few if any new features.

First Impressions

One of the most noticeable changes becomes apparent when you begin installation on the new release. AutoCAD 2022 uses a new, simplified installer. In the past, users could perform custom installs and choose to install various tools and utilities. But with the 2022 release, there are no options other than choosing the folder where you install the program.

To create a deployment, perform a customized install or use a network license, you must log into your Autodesk

Fig. 1: AutoCAD 2022 (left) uses a simplified installer, whereas previous versions (right) offered multiple options. *Images courtesy of David Cohn.*

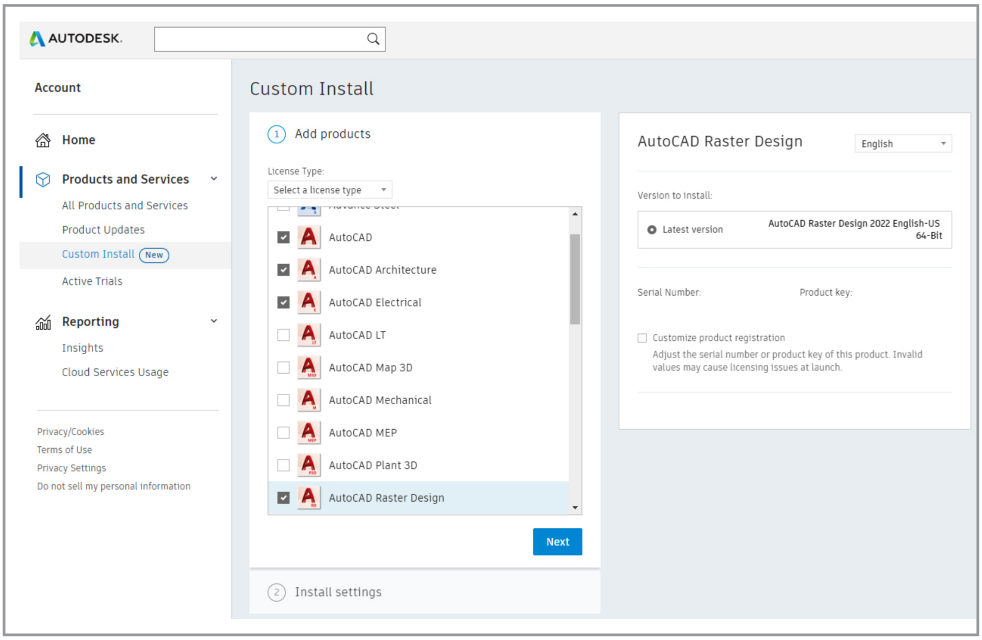


Fig. 2: Custom and network installations must be done from an online dashboard, but you can now install multiple toolsets at the same time.

account and then select the Custom Install option. These changes do make it easier for individuals to download and install the new software and the custom install allows you to install multiple toolsets simultaneously, whereas in the past each toolset had to be downloaded and installed separately.

The Start screen has been redesigned. The multiple Create and Learn pages are gone, replaced by a single screen with a large Recent files panel flanked by smaller side panels. These tools make it easier to continue where you left off, begin new work, learn about new features and engage in the Autodesk customer community.

Counting Objects

Counting objects in a drawing can be quite tedious. The new Count tool quickly and accurately counts instances of objects in a drawing. For example, to count instances of a single object, select the object, right-click and choose Count.

The program highlights all instances of the object and opens a Count toolbar that displays the number of instances. Tools on that toolbar enable you to zoom to the next or previous instance of the object, display details of the count in a new Count palette, create a text field that is set to the current count value and close the Count toolbar.

When the Count toolbar is closed, the Count palette displays a tally of all the blocks in the drawing. The totals update automatically as you modify the drawing. A special icon alerts you to any issues related to the reported count, such as overlapping or exploded blocks. The palette also includes a tool to insert a table containing the block names and corresponding count for each block in the drawing. The count list also includes blocks that are nested within other blocks. Only visible blocks in model space are displayed in the Count palette and the Count tool does not support some objects, including text, hatches, 3D objects and external references. Counting objects in drawings with lots of unique block names can slow program performance.

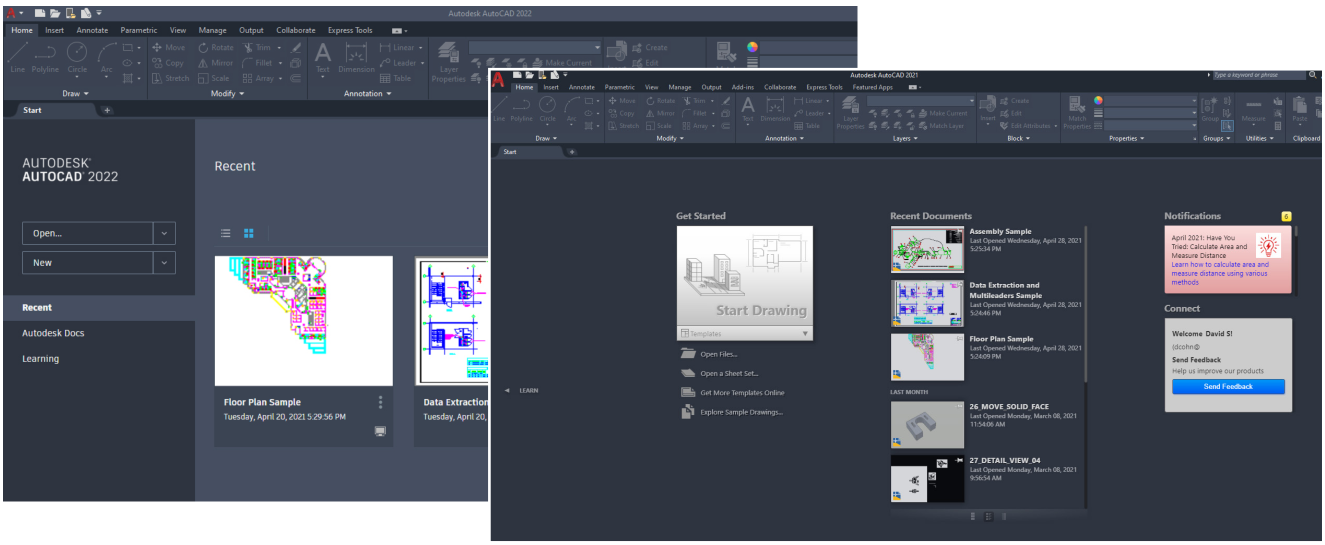


Fig. 3: The Start screen for AutoCAD 2022 (left) has been redesigned from the multi-page version used in previous releases (right).

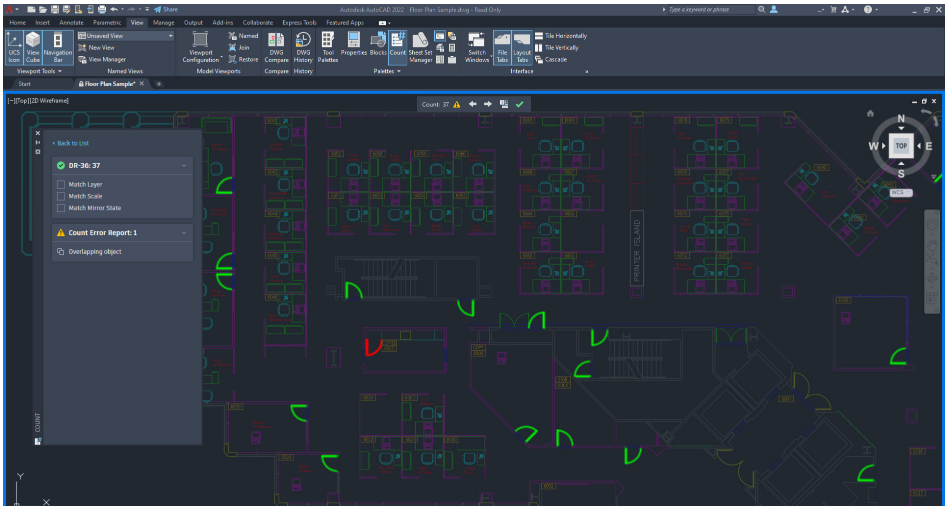


Fig. 4: The new Count tool tallies all blocks in a drawing and alert you of any issues, such as overlapping or exploded blocks.

Each open drawing appears with its own file tab. In previous versions, you could select a tab to switch between open drawings or display each in its own window, but those windows remained within the main AutoCAD window. AutoCAD 2022 now enables you to drag a drawing away from the AutoCAD application window and float it anywhere on screen, including onto an additional monitor. To reattach the drawing, simply drag it back to the tab area in the application window.

Trace, Share and Push

AutoCAD 2022's other new features all relate to collaborating with others via Autodesk applications. For example, the new Trace feature provides a safe space to add changes to a drawing in the AutoCAD web or mobile app without altering the existing drawing. After saving a drawing to web and mobile, a colleague can open the drawing and use the new Trace tool to mark up drawings using objects such as lines and arcs and annotation objects such as text and revision clouds.

Once another user saves their changes, when you use AutoCAD 2022 to reopen the drawing from web and mobile, the new Traces palette displays a list of traces along with who added the trace and when it was added, and individual traces can be deleted or renamed.

When you select a trace in this palette, a Trace toolbar appears at the top of the drawing window, and you see a view-only image of the trace. A button on the toolbar lets you toggle the trace to the front or back. You can then use standard AutoCAD commands to modify the actual drawing, not the trace itself. When you close the toolbar, the trace image disappears.

The new Share command shares a link to a copy of the current drawing that anyone with the link can access using the AutoCAD web app. The copy includes all external references and images. The link expires seven days after its creation and you can choose your permission level. With Share, rather than using ETRANSMIT to create a ZIP file containing all related drawing assets and then having to email or upload that file, you

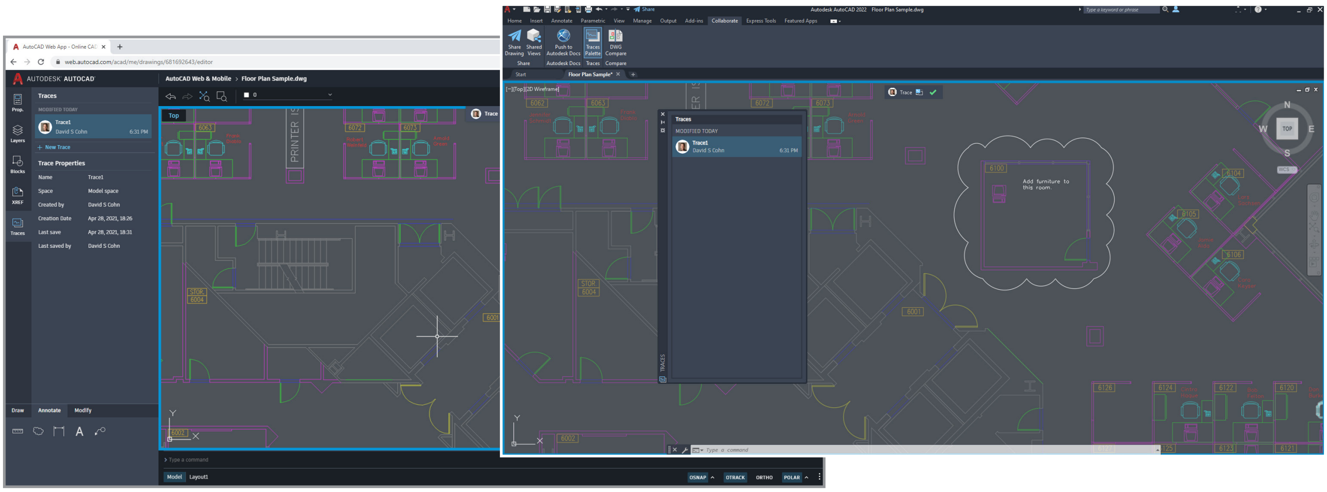


Fig. 5: After adding markups (traces) in the AutoCAD web and mobile app (left), you can view and respond to those markups using the new Traces palette in AutoCAD (right).

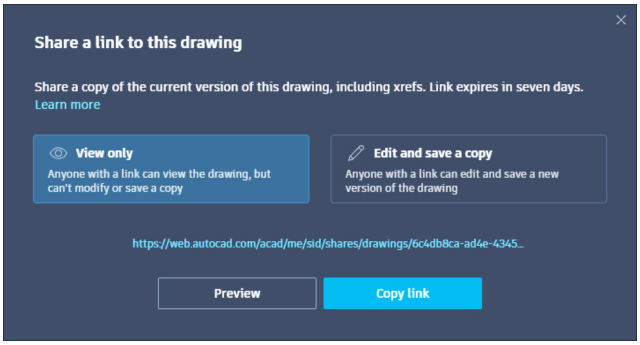


Fig. 6: Rather than emailing an entire drawing, the Share command lets you share a link to view or edit the file using the AutoCAD web app.

can simply send someone a link to the drawing.

Push to Autodesk Docs opens a new palette where you can select paper space layouts and then upload those sheets as PDF files to a selected folder on Autodesk Docs or BIM 360. The PDF files are then published and uploaded in the background. A balloon notification appears on the status bar once all the files have been published.

3D Tech Preview

AutoCAD 2022 also includes a technical preview of a new 3D graphics system being developed for AutoCAD that promises to leverage the power of modern graphics processing units and multi-core CPUs to offer a smoother navigation experience when working with large drawings. This feature is automatically turned off and requires you to restart AutoCAD for the change to take effect.

At present, this feature is only active when working in a 3D model with the Shaded visual style. This is also the only new feature not available in AutoCAD LT. All the other new commands (Count, Trace, Share, Push to Docs and floating windows) are also available in AutoCAD LT.

The 2022 release continues to use the same drawing file format as AutoCAD 2018, so DWG files remain 100% compatible. You can download a 30-day free trial of any of the new AutoCAD 2022 products from the Autodesk website. The cost of the software has again gone up slightly, but you can save up to 39% by opting for a one- or three-year subscription.

Once again, the new release does not offer much in the way of new features, but the enhancements that have been added should benefit all users, regardless of what they create. Since AutoCAD and AutoCAD LT are only available by subscription and the DWG file format has not changed, there is no reason not to upgrade. DE

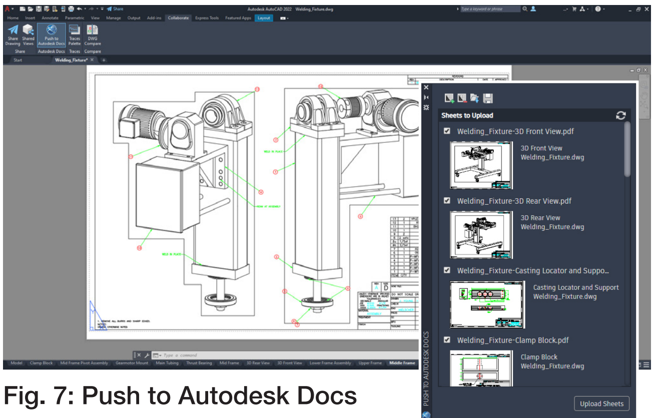


Fig. 7: Push to Autodesk Docs publishes sheets as PDF files to BIM 360 or Autodesk Docs.

David Cohn *has been using AutoCAD for more than 35 years and is the author of over a dozen books on AutoCAD. As senior content manager at 4D Technologies, he creates the CADLearning courses for AutoCAD and AutoCAD LT (www.cadlearning.com). He is a contributing editor to Digital Engineering, and also does consulting and technical writing from his home in Bellingham, WA. You can contact him at david@dscohn.com or visit dscohn.com.*

→ MORE INFO

- **Autodesk.com**
- **Prices:**

AutoCAD 2022 and AutoCAD LT 2022 are only available by subscription. Upgrade pricing and perpetual licenses are no longer available.

AutoCAD 2021

Monthly	$220.00
1 Year	$1,775.00
3 Years	$4,795.00

AutoCAD LT 2020

Monthly	$55.00
1 Year	$440.00
3 Years	$1,190.00

- **System Requirements**

Operating System: 64-bit OS that follows Autodesk's Product Support Lifecycle policy

CPU: 2.5GHz processor or faster (3.0GHz or faster recommended)

Memory: 8GB (16GB recommended)

Disk Space: 10GB free disk space for installation

Display Resolution: 1920x1080 with True Color (resolution up to 3840x2160 supported on Windows 10 64-bit systems)

Display Card: 1GB GPU with 29GB/s bandwidth and DirectX 11 compliant (4GB GPU with 106GB/s and DirectX 12 compliant recommended)

Specialized toolsets require additional memory and disk space.

For more information on this topic, visit DigitalEngineering247.com.

Real-Time Ray Tracing Redux

The NVIDIA RTX A6000 outperforms its predecessor.

BY DAVID COHN

In October 2020, at its GPU Technology Conference (GTC), NVIDIA introduced its new flagship graphics processing unit (GPU) for creators—the NVIDIA RTX A6000—and ushered in second-generation RTX graphics boards. Built on the new NVIDIA Ampere architecture, the RTX A6000 enables users to complete complex creative tasks, such as video editing in 8K HDR in real time and animating extra-large 3D models.

With 48GB of discrete memory, the RTX A6000 offers the largest memory available in a single GPU and is expandable to 96GB using NVLink to connect two GPUs.

The board became available at the end of 2020, and we received a unit to review earlier this year. Those familiar with the previous generations of professional graphics solutions from NVIDIA may have noticed the lack of the Quadro name for the RTX A6000.

While NVIDIA has stopped using the Quadro brand name to identify its professional solutions, the RTX A6000 offers all the professional features and benefits users have come to expect from previous Quadro products. The RTX A6000 features the same hardware and software certifications and uses the same drivers for professional applications.

A Giant Leap

The new Ampere architecture provides a "giant leap in performance," according to NVIDIA. Fabricated on Samsung's 8nm NVIDIA custom process, the board packs 28.3 billion transistors into a die size measuring 628.4 mm^2, compared to 18.6 billion transistors packed into 754 mm^2 using a 12nm process in the Quadro RTX 6000.

The new architecture features an improved streaming multiprocessor (SM), second-generation ray tracing (RT) cores for improved ray tracing hardware acceleration, third-generation Tensor Cores for increased artificial intelligence (AI) inference performance and Deep Learning Super Sampling (DLSS) improvements that enhance performance at higher resolutions.

The SM features double the 32-bit floating point (FP32) performance compared to the previous generation. Graphics and compute operations and algorithms benefit from the FP32 improvements as do modern shader workloads and ray tracing denoising shaders. The heavier the ray tracing rendering workload, the bigger the performance gains relative to the previous generation, according to NVIDIA.

The RTX A6000 GPU is essentially three processors in one: a programmable shader, the RT Core that accelerates ray-triangle and ray-bounding box intersections and the AI processing Tensor Core. The NVIDIA Quadro RTX 6000 was the first GPU to combine all three processors, which lays the foundation for the future of real-time ray tracing (RT) and the move away from rasterization, a technology invented in 1974. Ray tracing brings a level of realism far beyond what was possible using rasterization.

During the introduction of the RTX 6000 at SIGGRAPH 2018,

Fig. 1: The NVIDIA Quadro RTX 6000. *Images courtesy of David Cohn.*

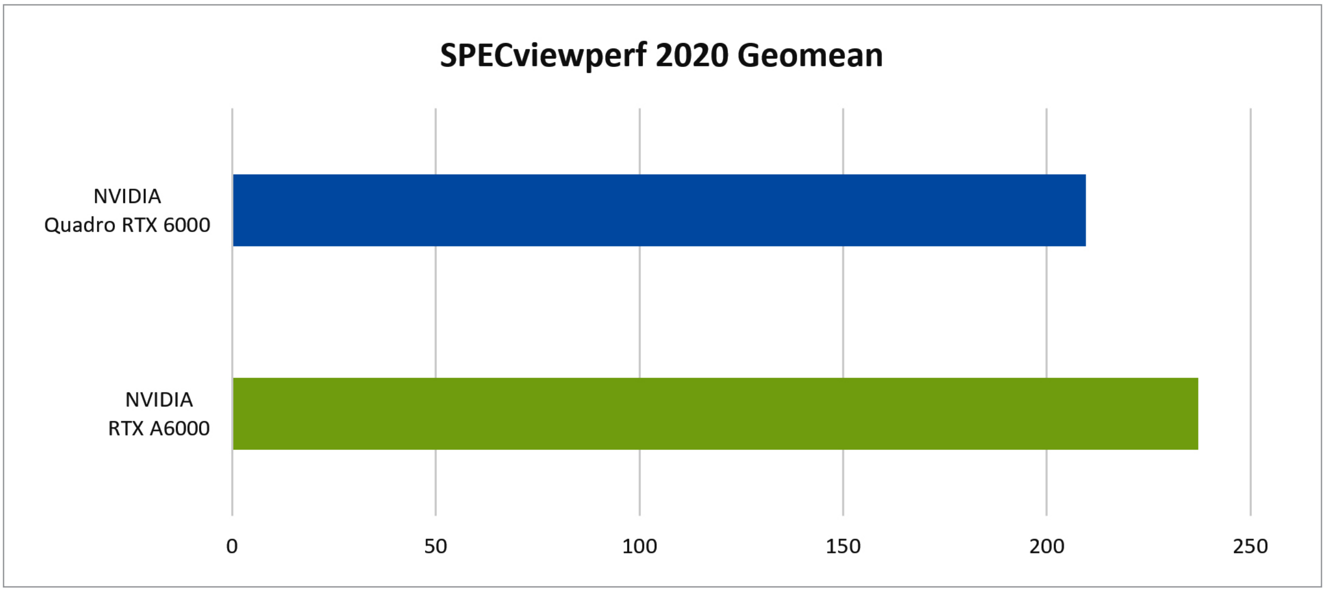


Fig. 2: The performance of the NVIDIA RTX A6000 compared to the Quadro RTX 6000.

NVIDIA CEO Jensen Huang stated that, "the arrival of real-time ray tracing is the Holy Grail of our industry."

The new RTX A6000 performs two shader calculations per clock versus one in the previous generation. The second-generation RT core doubles ray-triangle intersections over the RTX 6000. And the third-generation Tensor core automatically identifies and removes less important deep neural network (DNN) weights and processes the sparse network at twice the rate of its predecessor.

Accelerated Motion Blur

The RTX 6000 was the first to enable acceleration for real-time RT and professional final frame rendering using industry-standard rendering engines such as Arnold and Vray. The new board provides even faster ray-traced rendering performance. A single RTX A6000 board can render complex models with physically accurate shadows, reflections and refractions. Ray tracing is up to twice as fast compared to the RTX 6000. The A6000 also supports hardware-accelerated motion blur.

Motion blur is used to enhance the final image's realism when users render moving objects. Because the shutter systems on physical cameras cannot freeze the motion of moving objects, motion blur occurs naturally in still images and movies, helping to convey movement and giving the viewer clues about the speed of objects.

The render engine can add motion blur during the rendering process, or users can add it as a post-processing effect. Computing motion blur during rendering produces exceptionally high-quality results, but in the past this significantly increased render times. Approximating motion blur by implementing "vector blur" has been used as a post-processing alternative. But while this results in faster rendering, it can introduce unwanted visual artifacts.

With the introduction of accelerated motion blur on the new RTX A6000, artists can take advantage of the higher quality provided by rendered motion blur, with less impact on render times. In one example quoted by NVIDIA, it took 291 seconds to render a scene with motion blur using the RTX A6000 versus 841 seconds on the RTX 6000.

More Power Required

Like its predecessor, the new NVIDIA RTX A6000 is a full-height, full-length, dual-slot board with four DisplayPorts. Gone, however, is the VirtualLink connector, a USB Type-C port included on the first-generation Quadro RTX boards to attach virtual reality (VR) headsets. Still, the A6000 is VR-ready and can drive up to four 4K displays at 120Hz, four 5K displays at 60Hz, or two 8K displays at 60Hz.

You can also add an NVIDIA Quadro Sync II board to connect as many as four Quadro GPUs in a single workstation to support up to 16 displays or projectors per system or use two Quadro Sync II boards to connect eight Quadro GPUs to support video walls with up to 32 displays. The Quadro Sync II also offers the ability to generate an external house sync signal output via a BNC connector, eliminating the need for external sync generation hardware.

As previously mentioned, the NVIDIA RTX A6000 includes 48GB of GDDR6 error-correcting code memory, compared to 24GB in the Quadro RTX 6000. The amount of GPU memory directly impacts the size of datasets that can be visualized or analyzed. The A6000 provides 10,752 compute unified device architecture (CUDA) cores (compared to 4,068 in the RTX 6000). There are actually fewer Tensor Cores in the A6000 (336 compared to 576 in the RTX 6000), while the number of RT Cores has increased from 72 to 84.

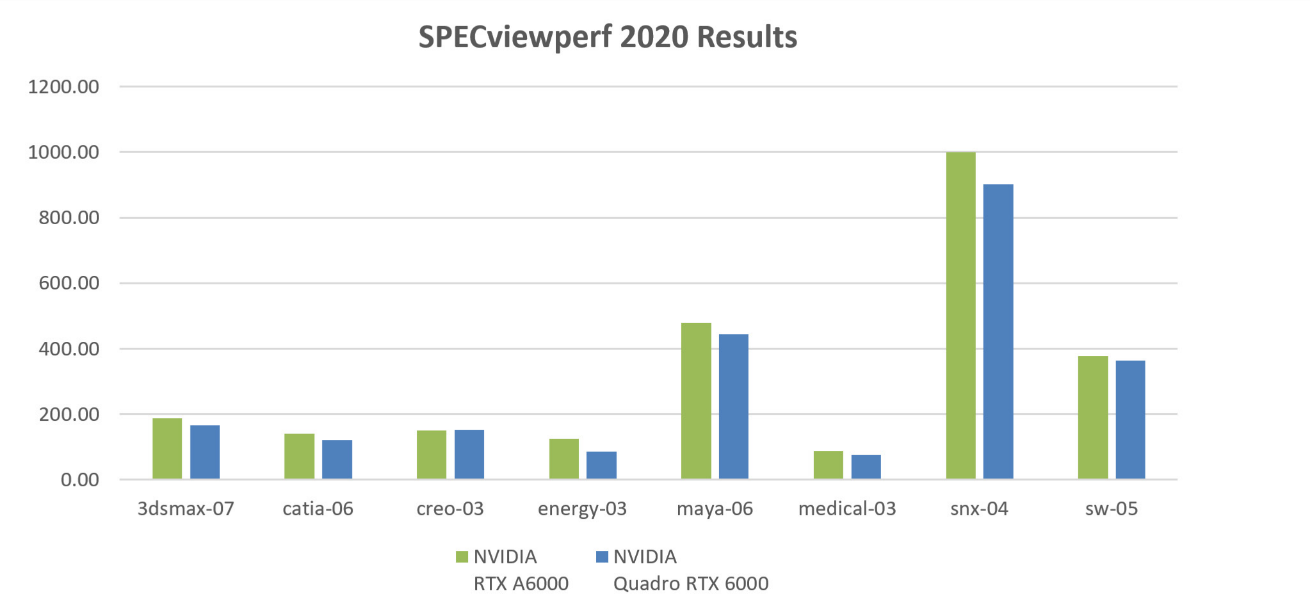


Fig. 3: SPECviewperf results for the NVIDIA RTX A6000 compared to the Quadro RTX 6000.

The new RTX A6000 consumes a bit more power than the RTX 6000 (300 watts versus 260 watts). While the RTX 6000 used a 14-pin PCIe auxiliary power connection, the A6000 has a single eight-pin EPS (entry-level power supply) power port that can be connected directly to the system power supply. NVIDIA supplies an adapter so that the board can be powered by two 8-pin PCIe power cables if an 8-pin CPU power cable is unavailable.

The new third-generation NVIDIA NVLink allows peer-to-peer communication between two RTX A6000 GPUs at speeds of up to 112.5 GB/s. The new board is also the first NVIDIA professional graphics board to support PCI Express Gen 4, which provides up to twice the bandwidth of the previous generation.

Testing the Board

With the arrival of the NVIDIA RTX A6000, we quickly set about the task of testing the new board and comparing it to the previous generation. We used SPECviewperf 2020, the latest version of this graphic benchmark, and tested both boards using a Lenovo ThinkStation P620 workstation powered by a 2.7GHz AMD Ryzen Threadripper Pro 3995WX 64-core CPU and equipped with 32GB of 2666MHz DDR4 error-code correcting (ECC) memory.

We also retested the NVIDIA Quadro RTX 6000 graphics board in this same workstation using the latest version of the NVIDIA driver, which supports both the RTX A6000 as well as the previous generations of Quadro RTX boards. The RTX A6000 clearly outperformed the Quadro RTX 6000.

With a suggested retail price at launch of $4,650, the new RTX A6000 is also undoubtedly superior from a price/performance standpoint. But good luck finding an A6000 at that price. When it was first introduced, the RTX 6000 had an MSRP of $6,300, but was readily available at $4,000. The A6000, on the other hand, currently has a street price around $5,500.

Like all previous NVIDIA Quadro boards, the RTX A6000 is independent software vendor certified, and its unified video driver is available for 64-bit versions of Microsoft Windows 10, 8.1, 8 and 7; Windows Server 2012, 2016 and 2019; and Linux, Solaris x86 and FreeBSD. The new board is also backed by a three-year warranty.

Once again, NVIDIA has introduced a new GPU that delivers unprecedented levels of performance. DE

David Cohn *is the senior content manager at 4D Technologies. He also consults and does technical writing from his home in Bellingham, WA and has been benchmarking PCs since 1984. He is a Contributing Editor to Digital Engineering and the author of more than a dozen books. You can contact him via email at david@dscohn.com or visit his website at www.dscohn.com.*

→ MORE INFO

- **NVIDIA:** NVIDIA.com

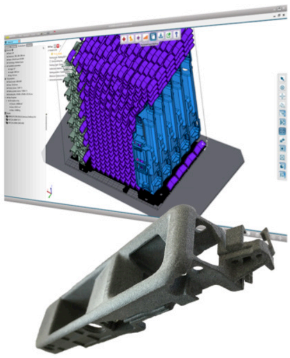
NVIDIA Quadro RTX A6000

- **Price: $4,650 MSRP**

For more information on this topic, visit DigitalEngineering247.com.

EDITOR'S PICKS

Each week, DE's editors comb through dozens of new products to bring you the ones we think will help you do your job better, smarter and faster. Here are our most recent musings about the products that have really grabbed our attention.



3D Printing Automated Production

Tool works with data from major CAD formats and outputs to various 3D printers.

CoreTechnologie introduces an update to its universal 3D printing software 4D_Additive that simplifies small-batch production of 3D printed parts. Version 1.3 features a revised texture module, used to enhance the surfaces of CAD models or STL bodies. Users may apply their own texture designs, or draw from the software's library of more than 5,000 predefined patterns. Logos, QR codes, text and part ID numbers, can also be generated and placed on a surface.
MORE → digitalengineering247.com/r/25166

Upgrade to Mixed Reality 3D CAD Viewing Suite

Theorem-XR Suite update supports HoloLens 2, Microsoft Azure Remote Rendering.

Theorem Solutions has released a major update to its Theorem-XR Experience Suite and Visualization Pipeline. Theorem-XR enables visualization of 3D CAD and PLM assets in context and at full scale for a range of engineering task-based use cases. It supports various devices and data types for augmented reality, virtual reality and mixed reality. The Visualization Pipeline provides a fully automated process that takes 3D data assets directly into Theorem-XR, or for the creation of Unity or Unreal assets for use in internally developed XR solutions. **MORE →** digitalengineering247.com/r/25141

Experience Automated 3D Printing Throughput

Modular 3D printer is part of a line designed for use by high-volume manufacturing.

Mosaic Manufacturing introduces Array modular 3D printing system for plastics. The company says Array offers lower costs in material use, extends uptime and can work with multiple materials. The Array line is designed for use by high-volume manufacturing facilities. The system features automated bed changing and material handling systems. It works with plastics including PEEK (polyether ether ketone), PEKK (polyether ether ketone ketone), Ultem and various Nylons.
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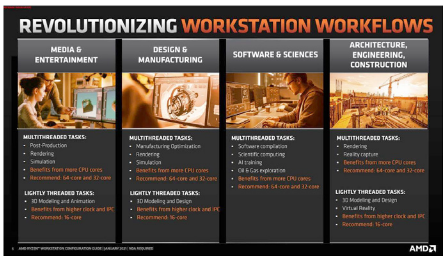
Power Runs AMD Threadripper Pro Workstation

Supermicro tower model holds latest AMD Ryzen CPU.



Supermicro's latest workstation is a tower model based on the latest generation AMD Ryzen Threadripper Pro CPU. This new CPU offers up to 64 cores and 8 memory channels. AMD builds this CPU using 7nm technology. The Supermicro A+ SuperWorkstation 5014A-TT will be delivered as a rack-ready tower workstation. The Ryzen Threadripper Pro is a single-socket CPU, built for high performance in applications where the CPU is more important than the GPU.
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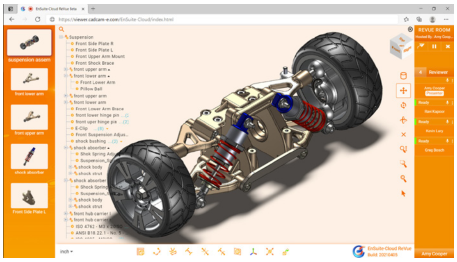

Conduct Secure Engineering Design Reviews

EnSuite-Cloud ReVue is a secure real-time peer-to-peer CAD collaboration product.

The new 3D collaboration software from CADCAM-E (CCE) enables users to perform engineering design reviews using 3D multi-CAD data such as NX, SolidWorks, Catia, Creo and more in the browser. No need for software installation or browser extensions. No CAD licenses are required for collaboration. Also, users don't need to upload native, exclusive design data. Users can buy an annual subscription for an "Organizer" license.

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Upgrade for Popular Electromagnetic Analysis Suite

There are updates in how software organizes setup of new, pre-existing models.

Integrated Engineering Software's 11.0 upgrade is for all software tools in its electromagnetic analysis suite. It focuses on more efficient operations in the Multiphysics program, including 2D, axisymmetric and 3D geometries. Changes span electric, magnetic, thermal and particle trajectory applications. Other highlights are new application programming interface functions to improve transfers to and from IES applications. Also, 3D models now use self-adaptive solving by default.

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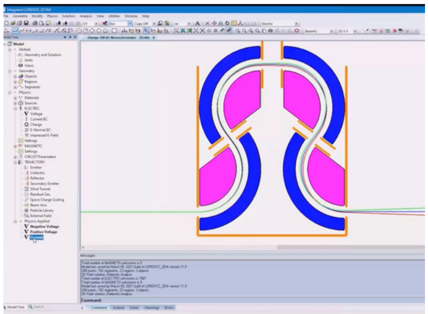

Access Powerful Enterprise Mobile Notebooks

AMD Ryzen PRO 5000 Series mobile processors feature CPUs with 7nm technology.

AMD makes available the Ryzen PRO 5000 Series Mobile Processor, which it describes as a groundbreaking improvement for new enterprise-class mobile notebook computers. This new series of CPUs is paired with AMD PRO technologies, a series of multi-layer security features and productivity enhancements. AMD expects broad availability of new enterprise-class mobile computers from HP and Lenovo, among others, starting in 2Q21.

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Boutique Workstation Group Delivers Threadripper

Velocity Micro says this workstation is ideal for compute-intensive applications.

Workstation vendor Velocity Micro introduces the ProMagix HD150 workstation equipped with the new, critically praised AMD Ryzen Threadripper PRO. At the heart of this new workstation is AMD's most ambitious CPU ever, the Threadripper PRO 3995 WX. It comes equipped with up to 64 physical cores, 128 processing threads, 128 PCIe Gen 4 lanes, and up to 2TB RAM. The AMD Ryzen Threadripper PRO comes in three models, all available in the ProMagix HD150.

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Next-Gen Engineers

Student Competition Profile: The Cornell Cup

Mastering the Cornell Cup

BY JIM ROMEO

The Cornell Cup has earned international recognition for its success in empowering students and developing world-class professional design skills among entrants. With primary sponsorship from semiconductor designer Arm, Cornell conducts the Cup during the academic year. Cornell works with sponsors to develop sponsored themes. Invitations are sent to student teams at the top 200 universities in the U.S. and Canada. David R. Schneider helps direct the Cornell Cup. He is director of mechanical engineering studies in systems engineering at Cornell University in Ithaca, NY.

***Digital Engineering:* Can you provide an overview of the Cornell Cup competition?**

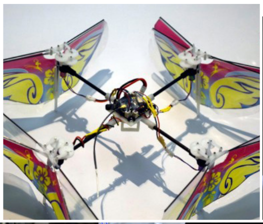
David Schneider: The Cornell Cup's students and the competition itself have earned some remarkable recognition over the years. The Cornell Cup competition was highlighted as one of seven university efforts in the 2015 White House Fact Sheet of Making and then repeated as one of nine university efforts in 2016, out of 1,500 university and K-12 efforts seriously considered.

Teams of three to five students compete and as many as 35 finalist teams have competed in final events.

***DE:* Does Cornell Cup have a particular stance on adopting an innovation that is linked to the program?**

Schneider: Although themes are suggested some years by sponsors, and special awards [are] offered, teams can propose any embedded systems/IoT project they would like towards the competition's main awards. With this flexibility, students first present the challenge they are trying to solve and what any solution would have to do to solve that challenge. Then when they describe their solution, they must describe how it meets the challenge's needs.

Then they must take things one step further to say this is how they would measure the performance of any solution to their challenge and then use those performance metrics to demonstrate why their solution is one of the best—if not the best—solution for meeting that challenge.



Entries in the Cornell Cup Challenge must solve student-identified engineering challenges. Entries pictured from prior events include the Flapping-Wing Micro Air Vehicle (University of California, Irvine), a quadcopter with four sets of ornithopter wings; the S.S. MAPR, which was designed to gather water quality samples automatically; and Terra Nova Rover, which can handle rough terrain and could be used in space and Earth-bound applications. *Images courtesy of Jim Romeo.*

***DE:* Anything else you'd like to tell us about the event?**

Schneider: Unfortunately, the competition did not run last year due to COVID-19, and our website is on hold, but we are gearing up for an even bigger year [in the] fall [2021].

Student teams respond with proposals in September and October. Teams present progress and receive highly valued industrial feedback in January/February in the online semifinals. Finalists are selected in February to attend and demonstrate their project in the finals event in May and then at TechCon in October of the following academic year.

The beginning of many students' entries can come from course or capstone projects that they have started in their schools and then the competition helps to elevate the students' experience and the quality of their inventions.

Examples of projects have ranged from emergency room drug identification systems, search & rescue amphibious robotics, rehabilitation prosthetics, autonomous water quality surveying systems, smart home energy control systems, automotive collision avoidance systems, educational robotic platforms, novel drive systems for autonomous drones, 3D printing for construction systems and theme park simulators. **DE**

Editor's Note: For anyone who would like to know more about the Cornell Cup, email drs44@cornell.edu.

→ MORE INFO

- **Cornell Cup:** CornellCup.SystemsEng.Cornell.edu