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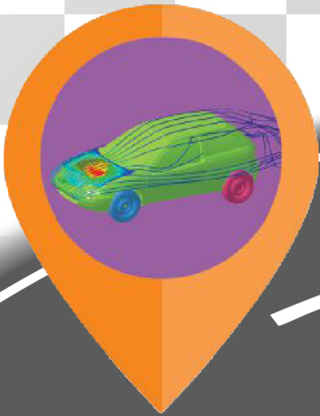
November 2016



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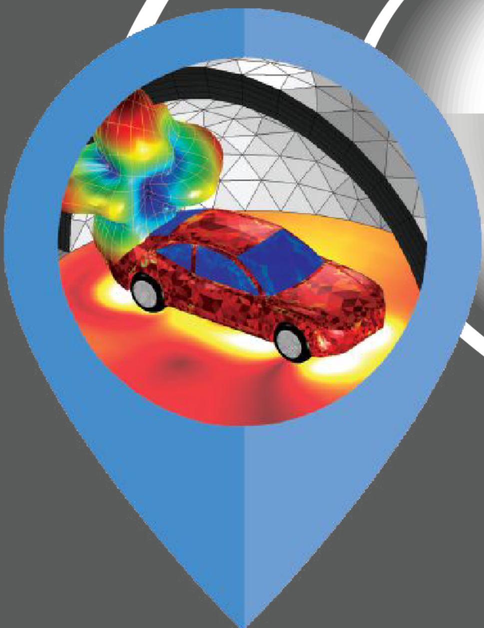

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by Jamie J. Gooch

The Supercomputer **Software Race**

IT'S NOVEMBER, AND OUR THOUGHTS TURN to autumn leaves, pumpkin pie and supercomputers. This month, the Top500 biannual ranking of the world's fastest, publicly known supercomputers will be updated. The list's release will coincide with SC16, the International Conference for High Performance Computing, Networking, Storage and Analysis in Salt Lake City from Nov. 13-18.

In the last Top500 update in June, China maintained its grip on the No. 1 spot with a surprising new supercomputer, the Sunway TaihuLight, which reached 93 petaflop/s (quadrillions of calculations per second) on the LINPACK benchmark. The TaihuLight dethroned China's Tianhe-2 supercomputer that had held the top spot for six years. It is twice as fast and three times as efficient as the Tianhe-2, which in turn is almost twice as fast as the fastest U.S. supercomputer on the list, the Titan, a Cray XK7 system installed at the Department of Energy's Oak Ridge National Laboratory. (See page 7 for the rankings.)

Unlike the Tianhe-2, which runs on Intel processors, the TaihuLight runs on China's own ShenWei SW26010 processor with 260 cores per chip. Last year, the U.S. banned the export of some high-end Intel Xeon chips to China for use in supercomputers, but the country has been producing its own chips for many years. A ShenWei-based supercomputer first appeared on the Top500 list in 2011.

Not only has China outdone itself in terms of the fastest supercomputer, it is also now home to the largest number (167) of supercomputers on the list, besting the U.S. by two. This year marks the first time since the Top 500 rankings began 23 years ago that the U.S. cannot lay claim to the most machines on the list. So has the U.S. lost its edge? Is the supercomputing race over and done? Not even close.

Scaling the Software Summit

In 2014, Oak Ridge National Laboratory (ORNL) announced it would develop the Summit supercomputer using IBM Power9 CPUs, NVIDIA Volta GPUs and Mellanox EDR InfiniBand interconnects. ORNL says Summit will deliver more than five times the computational performance of Titan when it arrives at the Oak Ridge Leadership Computing Facility in 2017. It is expected to be ready for use in 2018, giving the U.S. a supercomputer that would double the current speed of the Sunway TaihuLight.

But what good will Summit's 3,400 nodes and 200 petaflops be if there is no software ready to use them? Hardware specs and LINPACK scores are great for comparisons, but they don't show who is best using supercomputers to solve real-world problems.

"The strength of the U.S. program lies not just in hardware capability, but also in the ability to develop software that harnesses high-performance computing for real-world scientific and industrial applications," the DOE said in a statement after the Top500 list was released in June. I tend to agree.

In addition to using supercomputers for energy and national security concerns, the DOE says its supercomputers are being used by industry to achieve the most practical results. These include Pratt and Whitney improving the fuel efficiency of its Pure Power turbine engines; Boeing studying the flow of debris to improve the safety of a thrust reverser for its new 787 Dreamliner; GM accelerating research on thermoelectric materials to help increase vehicle fuel efficiency; and GE improving the efficiency of its turbines for electricity generation to name a few.

Investing in Exascale

The U.S., China, France and Japan all have plans to achieve exascale computing—systems capable of a billion billion calculations per second—by 2020 and 2023. This would be a computing milestone, and the U.S. is bringing up the rear with its plans to hit exascale coming to fruition in 2023.

But again, that's not the whole story. It's not like current simulation software can just be run on future exascale architectures. The real winners of the exascale race will be the countries and organizations that invest in developing applications that can make use of all that computing power. That race has already begun.

In September, the DOE's Exascale Computing Project (ECP) announced its first round of funding. It awarded $39.8 million to 15 application development proposals for full funding and seven proposals for seed funding. The fully funded proposals include titles like "Transforming Additive Manufacturing through Exascale Simulation," "Exascale Deep Learning and Simulation Enabled Precision Medicine for Cancer," and "Transforming Combustion Science and Technology with Exascale Simulations." Those are more exciting than any number of nodes and flops, and it's only the beginning. **DE**

Jamie Gooch *is editorial director of* Digital Engineering. *Contact him via de-editors@digitaleng.news.*


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Digital Engineering

TECHNOLOGY FOR OPTIMAL ENGINEERING DESIGN

INSIDE

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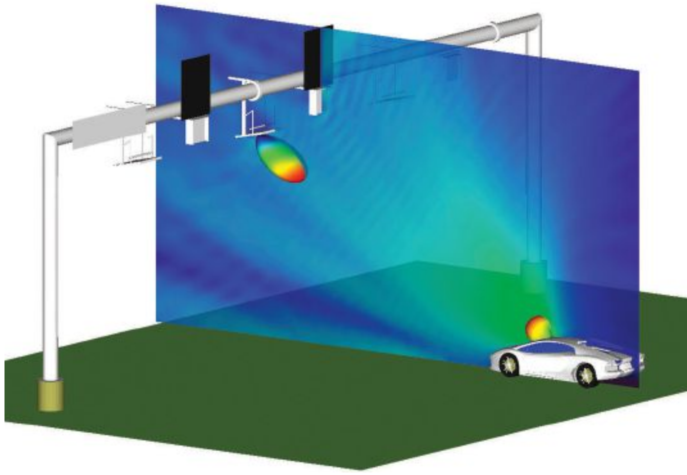
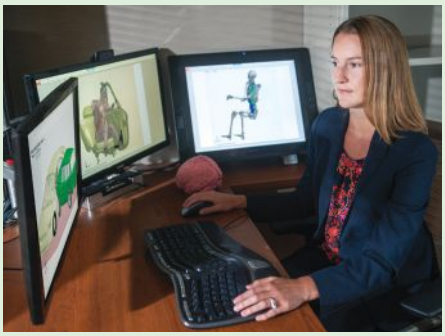


FOCUS ON ENGINEERING COMPUTING



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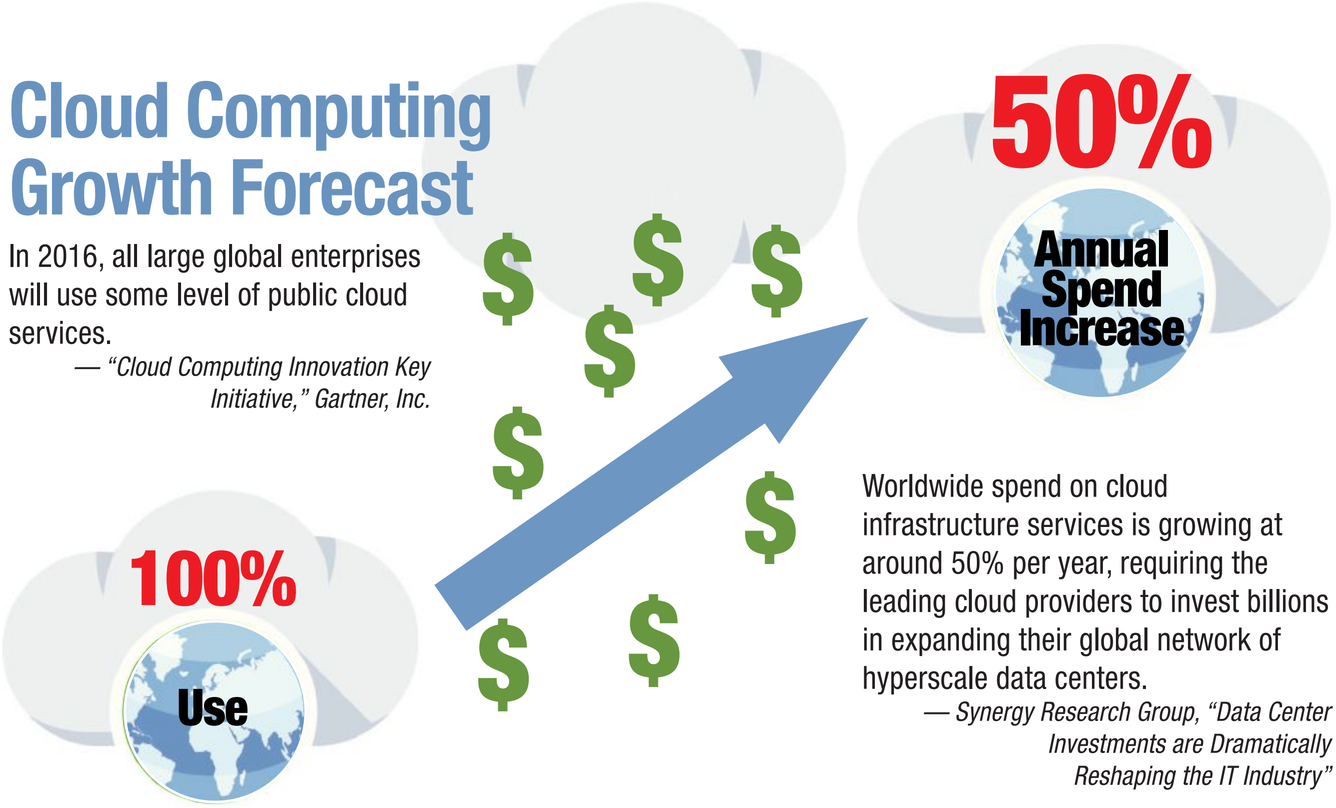
Cloud Computing Growth Forecast

In 2016, all large global enterprises will use some level of public cloud services.

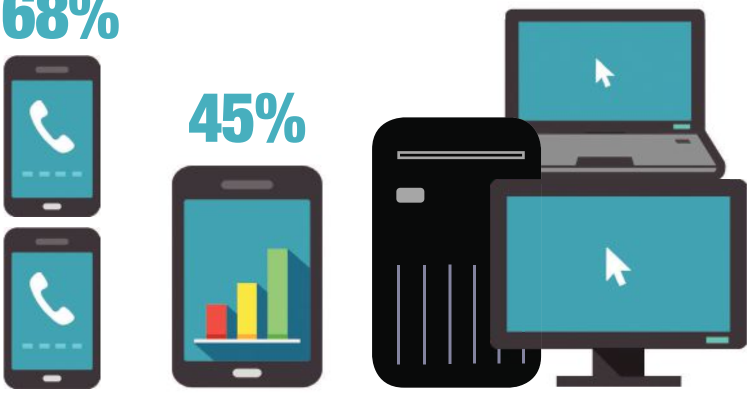
— *"Cloud Computing Innovation Key Initiative," Gartner, Inc.*



Worldwide spend on cloud infrastructure services is growing at around 50% per year, requiring the leading cloud providers to invest billions in expanding their global network of hyperscale data centers.

— *Synergy Research Group, "Data Center Investments are Dramatically Reshaping the IT Industry"*

Ownership

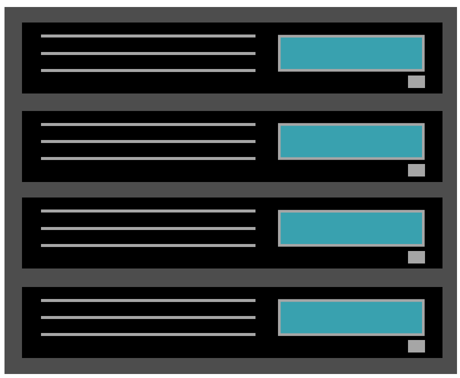


68% of U.S. adults have a smartphone, up from 35% in 2011; 45% own a tablet computer and 73% own a desktop/laptop computer, which is down slightly from a high of 80% in 2012.

— *"Technology Device Ownership: 2015," Pew Research Center*

HPC Server Sales

$11.4 Billion



High-performance computer server sales grew by 11% in 2015, reaching $11.4 billion. The forecast for 2015-2020 server growth is 5.9%.

— *"HPC Market Update," IDC 2015*

Testing Time

Computational modeling and supercomputers have enabled a 50% reduction in wind tunnel testing for new aircraft development.

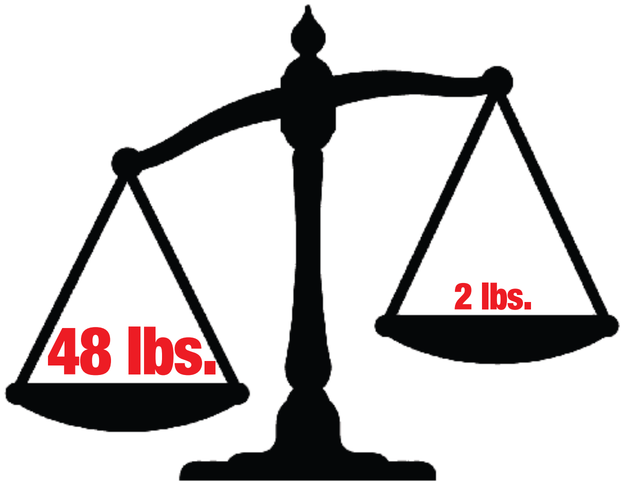
50% ↓

— Joseph, Dekate, and Conway, "Real-World Examples of Supercomputers," IDC 2014

2+ Years
25% Costs ↓

HPC modeling and simulation enabled Goodyear to reduce product design time from three years to less than one year and decrease tire building and testing costs by 25%.

— The Council on Competitiveness, "Goodyear High-Performance Computing" and "Success Stories: Goodyear," HPC For Energy via Information Technology & Innovation Foundation's "The Vital Importance of High-Performance Computing to U.S. Competitiveness."



The Xerox NoteTaker was developed in 1978 as a proof of concept for a portable computer. It weighed 48 lbs. There are now ultrabooks and laptops that weigh less than 2 lbs.

— history-computer.com

x1,000,000,000,000

Between 1956 and 2015 there was a 1 trillion-fold increase in computer processing power.

— "Processing Power Compared," Experts Exchange

10,649,600

Number of cores in the Sunway TaihuLight supercomputer at the National Supercomputing Center in Wuxi, China as of June.

— TOP500 list of the world's top supercomputers, June 2016

Rank	Site	System	Cores	Rmax (TFlop/s)	Power (kW)
1	National Supercomputing Center in Wuxi, *China*	Sunway TaihuLight - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway - *NRCPC*	10,649,600	93,014.6	15,371
2	National Super Computer Center in Guangzhou, *China*	Tianhe-2 (MilkyWay-2) - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P - *NUDT*	3,120,000	33,862.7	17,808
3	DOE/SC/Oak Ridge National Laboratory, *United States*	Titan - Cray XK7 , Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x - *Cray Inc.*	560,640	17,590.0	8,209
4	DOE/NNSA/LLNL *United States*	Sequoia - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom - *IBM*	1,572,864	17,173.2	7,890
5	RIKEN Advanced Institute for Computational Science (AICS) *Japan*	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect - *Fujitsu*	705,024	10,510.0	12,660

| ABBEY'S ANALYSIS |

FEA THEORY

by Tony Abbey

Who's on First: Hooke or Young?

I WAS TEACHING AN "Introduction to Finite Element Analysis (FEA)" training course in the Netherlands recently. A design engineer taking the course came up with a good question relating to a graph I had just sketched up on the whiteboard. I was describing how a material would respond to the loading, in terms of its stress and strain, as shown in Fig.1.

I had described the linear part of the graph as representing Hooke's Law, and then overlaid a triangle to show that the slope of the linear region of that curve is Young's Modulus. My questioner wanted to know "Why not Young's Law and Hooke's Modulus?"—the two seemed interchangeable. Well, the question underlined how easy it is to get confused between the context of the two definitions. So let's rewind, and think how I could've presented this in a better way.

Robert Hooke's Watch Springs

Robert Hooke (1635-1703) was the first of the two English gentlemen whose names we are considering. His experiments looked at the relationship between an applied force and the subsequent extension, using structural components. These were mainly simple linear or rotational springs. He was able to show that the relationship between the force and the resultant extension was linear over a large operating range. In particular, he was interested in the application of this to the response of helical watch springs. In fact, his clock inventions formed the basis for a lot of his early wealth.

Hooke's Law is therefore applied to structural components, from simple linear or rotational springs to much more complicated structures.

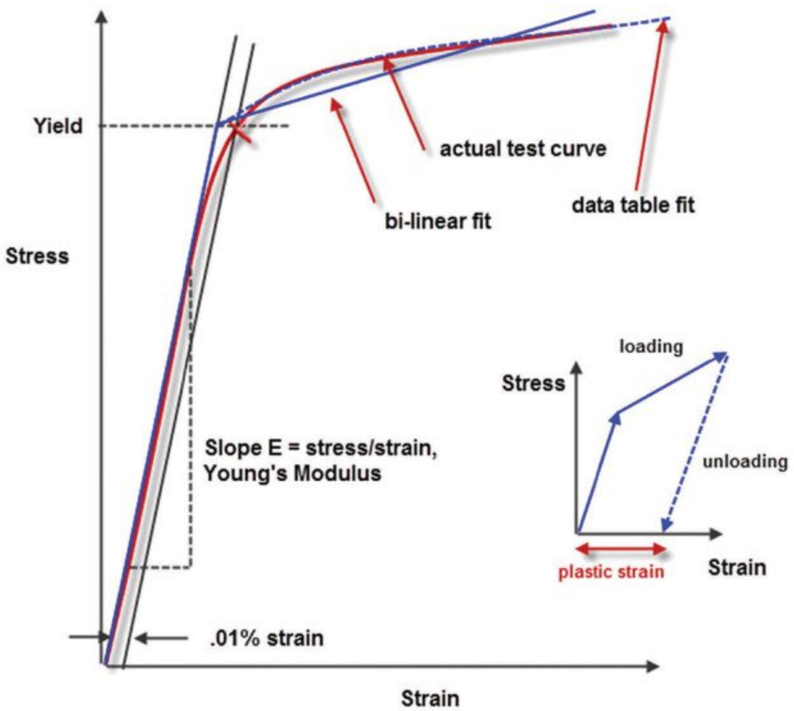


FIG. 1: A typical material stress-strain curve.

Application to Structures

For a rod under axial loading we can show quite easily the stiffness of the component rod is *AE/L*, where *A* is the cross-sectional area, *E* is Young's modulus and *L* is the length. So we can use Hooke's Law to derive *F=k*d*, or *F=(AE/L)*d*, where *k* is the rod axial stiffness, *F* is the applied force, and *d* is the deflection we solve for. The graph is shown in Fig. 2. This is a single degree of freedom (SDOF) solution.

In an FEA simulation more complex structures, with many DOF, are loaded. The complete load vs. deflection relationship is defined by the system stiffness matrix. The system stiffness matrix is derived by assembling the stiffness matrix of all the elements. So now *{F}= [K]*{d}*, where *{F}* is the applied load vector, *[K]* is the system stiffness matrix and *{d}* is the vector of deflections we solve for. The complete structure follows Hooke's Law. We can in fact break out a single degree of freedom (SDOF), for example at a key deflection. If we plot the total load vs. deflection at this point, we can see Hooke's Law in action, as shown in Fig. 3. We can even evaluate the equivalent SDOF stiffness of a structure by loading that point and measuring the deflection, as shown in Fig. 4. This will now be analogous to the response of an equivalent spring stiffness. This is a useful method of assessing structural component stiffness in design. This technique allows us to compare load paths within a struc-

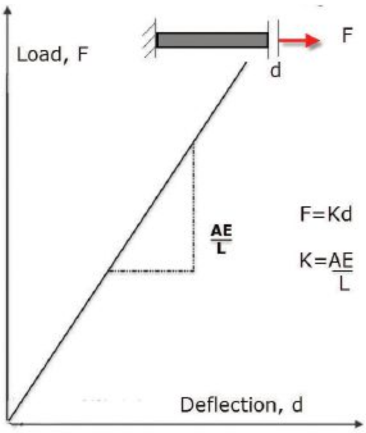


FIG. 2: Hooke's Law: Load vs. deflection for rod.

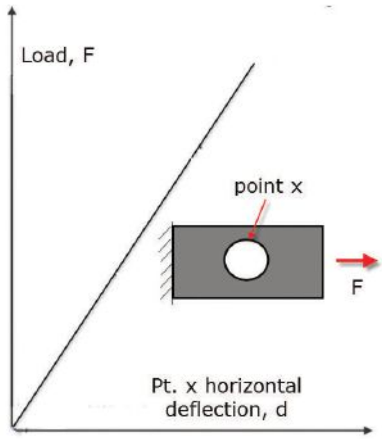


FIG. 3: Hooke's Law: Structural stiffness of component.

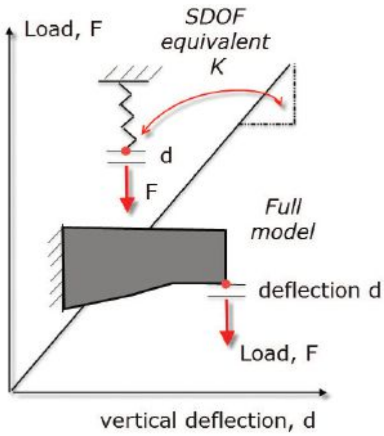


FIG. 4: Equivalent SDOF stiffness of structure.

ture, create boundary conditions, estimate modal stiffness and has other applications.

Thomas Young and Elasticity

So how did Thomas Young (1773-1829) get involved? He was concerned with the elasticity of the material itself. So this is much more specific than the general Hooke's law (which still applies). The linear relationship of the material is what we call Young's Modulus. He was one of the first researchers to realize that each type of material has its own inherent stiffness, and the relationship is named in honor of him.

The graph in Fig. 1 shows a typical uniaxial (1D) test result to evaluate Young's Modulus. A more general 3D stress strain relationship can be derived for Isotropic materials by using Poisson's ratio. This relates the axial strain to the transverse strain.

Hooke's Law is an overall structural stiffness term, dependent on the configuration, as well as the inherent material stiffness properties; whereas Young's Modulus is specifically the stiffness of the material itself.

So, to use the phrase from the old Abbott and Costello sketch—in our team, Hooke's on First! **DE**

Tony Abbey *works as training manager for NAFEMS, responsible for developing and implementing training classes, including a range of e-learning classes. Check out the range of courses available: nafems.org/e-learning.*

| MAKING SENSE OF SENSORS |

GYROSCOPES

by Tom Kevan

Selecting the Right Gyroscope

LAST MONTH'S COLUMN looked at the rise of motion sensing and its role in expanding the functionality of mobile devices. Against this backdrop, we reviewed the basics of accelerometer technology. This month, let's look at another leading motion sensor: The gyroscope, a technology that offers a way of measuring angular rotation across three axes, providing data on roll, pitch and yaw. In addition to measuring these parameters, design engineers can use a gyroscope to improve the accuracy of an accelerometer operating in the same inertial measurement unit.

While these features made traditional gyroscopes a logical candidate for mobile interfaces designed to serve context-aware applications, a few obstacles still remained. These included size and sensitivity. Before gyroscopes could achieve their full potential in mobile applications, sensor makers had to address these shortcomings.

Gyroscopes 101

Enter MEMS (micro-electro-mechanical systems) technology, a microfabrication technique that delivers greater sensitivity in a smaller form factor. By making the shift to MEMS-based devices, design engineers can take on a new class of applications, changing the mobile landscape in the process.

Although MEMS gyroscopes include piezoelectric- and laser-based designs, many rely on a tuning-fork configuration that uses the Coriolis effect to measure the angular rate. With this approach, the two tines of the tuning fork oscillate, moving in opposite directions. When angular velocity is applied, the Coriolis force on each tine acts in opposite directions, resulting in a change in capacitance proportional to the applied angular rate. The sensors convert this change in capacitance into output voltage for analog gyroscopes or LSBs for digital gyroscopes.

An important strength of this type of sensor is its ability to measure complex motion accurately in multiple dimensions. As a result, it can track the position and rotation of a moving object, unlike accelerometers that only determine that an object is moving in a particular direction. In addition, errors related gravitational and magnetic fields do not affect the performance of this type of gyroscope. Armed with these features, these sensors go a long way toward enabling advanced motion applications in consumer devices, such as gesture control.

Selection Criteria

The challenge for design engineers has been to identify the parameters that help them choose the most appropriate gyroscope for an application. While much has been written about nonlinearity, noise density and bias repeatability, experts generally consider bias instability and acceleration sensitivity to be the key parameters engineers should focus on during the selection process.

Bias instability describes the resolution floor of the gyroscope, specifying the device's detection limitations. The bias of a vibratory gyroscope represents the device's average output when it is at rest, a state referred to as the zero rate output. Bias instability measurements describe how the bias of a gyroscope changes over a specific period of time under constant temperature and pressure. These measurements are usually expressed in degrees per hour or degrees per second.

Designers must also consider sensitivity to acceleration and vibration because these forces affect the output of the gyroscope. Sensitivity results from asymmetries in the gyroscope's mechanical design or micromachining inaccuracies. Gyroscopes manifest acceleration sensitivity in several ways, and the degree of their reactions varies from one design to another. Sensitivity to linear acceleration—or g sensitivity—produces the most significant errors, especially in mobile devices.

Knowing the importance of these two parameters is half the equation. We also have to minimize the impact of error sources. Environmental factors like temperature adversely affect bias instability. Most MEMS gyroscope data sheets, however, specify the impact of temperature, so a designer can use this information to calibrate the application to compensate for this type of error.

Correcting for g sensitivity is another matter, and it often proves more difficult. The most common approach is to add a mechanical anti-vibration mount, where the gyroscope assembly is isolated by rubber. The trouble with the technique is that the mount can be difficult to engineer because of its flat response over a broad frequency range and the fact that vibration-reduction characteristics change over temperature and the operating life of the device. Ultimately, the most important step is to select a gyroscope based on its vibration-rejection capabilities. DE

Tom Kevan *is a freelance writer/editor specializing in engineering and communications technology. Contact him via de-editors@digitaleng.news.*

| **CONSULTANT'S CORNER** |

OPTIMIZATION

by Bruce Jenkins

Cloud HPC Makes Simulation-Driven Design Optimization More Accessible

A NEW WAVE OF YOUNG, visionary organizations and initiatives is making the power of cloud HPC (high-performance computing) resources readily available and accessible to engineering simulation and optimization software users—including many who could never before afford anything close to the full computing horsepower they needed and wanted to run those applications.

One example, San Francisco-based Rescale Inc., offers software platforms and hardware infrastructure that let companies execute engineering and scientific simulations. Its goal, it says, is to "help transform stagnant, on-premise resources into an agile, optimized cloud HPC platform."

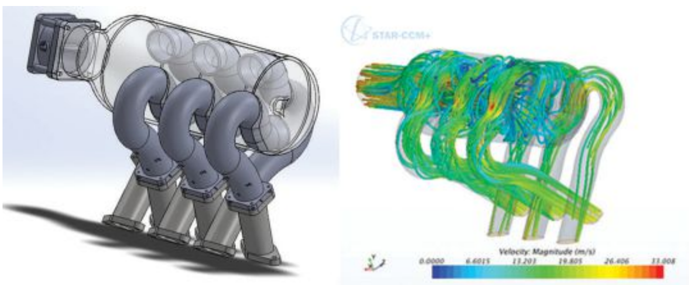
Rescale's cloud simulation and HPC platforms provide a wide range of software and hardware tools in one central location, giving engineers and scientists immediate and unlimited access to the exact resources they need. Rescale's extensive list of software partners gives users turnkey access to more than 160 simulation software packages. Pricing is either pay-as-you-go or users can employ their own license server.

Rescale explains its core value proposition: "The ability to fully explore the design space requires access to the latest technology in order to improve product conceptions. A team can generate more comprehensive results faster and yield better designs the first time around, giving an organization a significant competitive edge. Rescale's hardware and software elasticity speeds up product development and optimizes time-to-market."

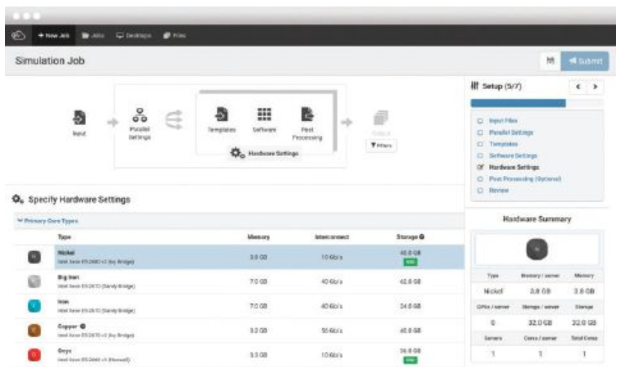
In one of the strongest signals yet for the increasingly central role that cloud HPC will play—indeed, is already playing—to expand the availability, affordability and value of CAE, the company recently received $14 million in Series A funding from an investor group led by TransLink Capital. In a press release, Rescale said the investment will support its expansion plans to "help meet the escalating worldwide customer demand for enterprise-class HPC platforms to help large enterprises transition from expensive legacy on-premise systems to a scalable, agile and high-performing cloud computing infrastructure."

Another prominent example is SimScale GmbH, provider of a cloud-based CAE platform accessible entirely through a standard web browser that lets users simulate, share and collaborate in its community of 65,000 engineering professionals. The company, headquartered in Munich, characterizes its mission as "harnessing the power of the cloud and cutting-edge simulation technology to build not just another simulation software but an ecosystem in which simulation functionality, content and people are brought together in one place, enabling them to build better products."

The SimScale platform supports an end-to-end simulation



UberCloud Experiment 187: CFD analysis of automotive V6 intake manifold using an UberCloud software container with STAR-CCM+ in the Azure Cloud. Left: manifold geometry. Right: velocity streamlines from CFD simulation. ***Image courtesy of CAE Technology Inc. and UberCloud.***



Rescale's SaaS web-based workflow is designed to be easy-to-use and includes pre/post-processing and remote desktop features. ***Image courtesy of Rescale.***

Tractor-trailer aerodynamic drag analysis executed on AweSim platform. *Image courtesy of AweSim.*

workflow starting with CAD model upload, CAD model preparation and automated mesh creation. Analysis types include structural mechanics of parts and assemblies (linear static, nonlinear and dynamic simulations, modal/frequency analysis), fluid dynamics, thermodynamics, particle dynamics and acoustics. After analysis, results can be visualized online in the SimScale post-processing environment, or downloaded.

Yet another example generating high interest is UberCloud, an online community and marketplace where engineers and scientists discover, try and buy on-demand computing power as a service. Engineers and scientists can explore and discuss how to use this computing power to solve their demanding problems, and to identify the roadblocks and solutions, with a crowd-sourcing approach, jointly with the UberCloud engineering and scientific community.

The UberCloud community offers free case studies, webinars and discussion forums to help users discover how to use computing power as a service to make their businesses more competitive. The UberCloud Experiment, aimed at users who need to run compute-intensive engineering and scientific simulations, offers free trials for up to 1000 CPU core hours on its computing clusters. The UberCloud Marketplace, a "one-stop-shop to get access to computing resources and fully bundled solutions, on-demand," offers "computing power and software-as-a-Service" for professional simulation projects. Finally, for software developers and providers—in-house, open-source and commercial—UberCloud develops ready-to-run Application Software Containers intended to ease the usability, accessibility and portability challenges in the development, execution and maintenance of engineering and scientific applications in public and private cloud environments.

A fourth such initiative is AweSim. A partnership among the Ohio Supercomputer Center (OSC), simulation and engineering experts and industry, its aim is to put simulation-driven design capabilities within reach of small to mid-sized manufacturers (SMMs). AweSim builds on OSC's former Blue Collar Computing initiative to offer a new level of integration and commercialization of products and services for SMMs.

AweSim Director Dr. Alan Chalker explains its mission: "Simulation-driven design replaces physical product prototyping with less expensive computer simulations, reducing the time to take products to market, while improving quality and cutting costs. Smaller manufacturers largely are missing out on this advantage, because they cannot afford to leverage such solutions. We aim to level the playing field, giving the smaller companies equal access." **DE**

Bruce Jenkins *is president of Ora Research (oraresearch.com), a research and advisory services firm focused on technology business strategy for 21st-century engineering practice.*

Simulating Everything Automotive

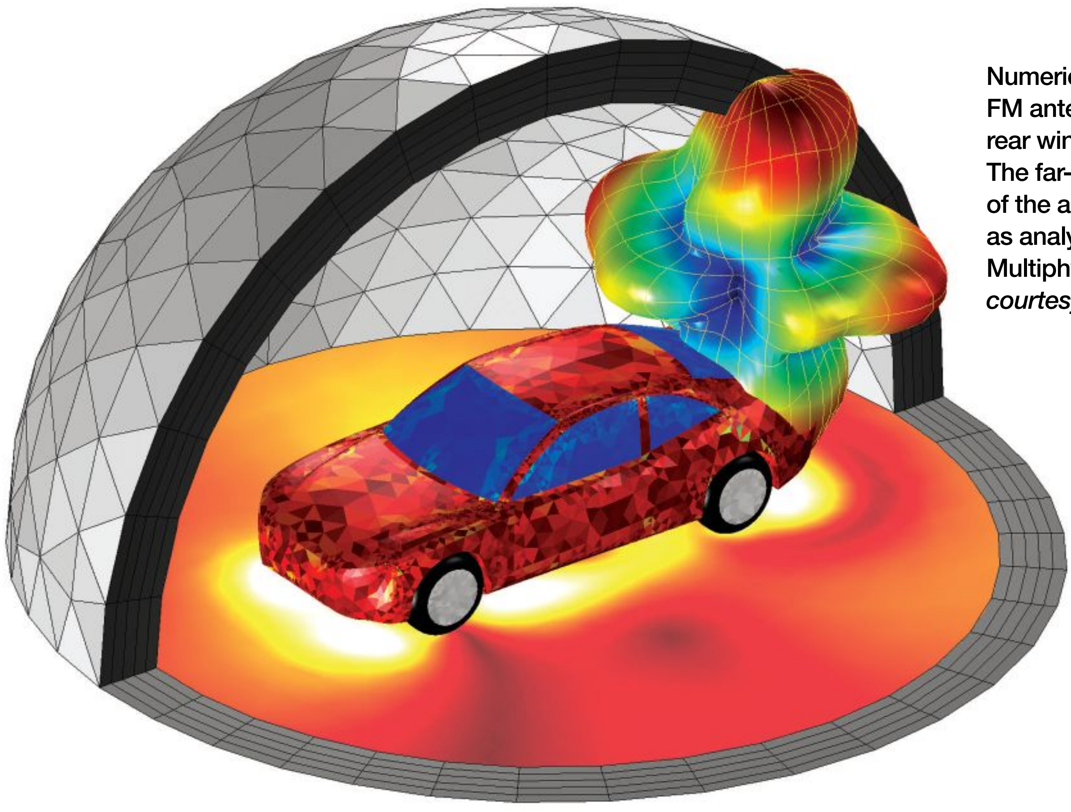
When did vehicles get so complex? Good thing today's simulation software tools are evolving to handle design, development, testing and deployment.

BY PAMELA J. WATERMAN

COVER STORY

THINK ABOUT THE MOST COMPLICATED SYSTEMS and structures on earth (and above). What comes to mind? The Three Gorges Dam? The Large Hadron Collider? The Space Shuttle or International Space Station? Now think instead about the car in your garage—or the one that will be there in a few years.

Automotive design encompasses some of the biggest technical challenges engineers have faced in the past 50 years, as vehicles have progressed from being mostly mechanical to electromechanical, to increasingly smart—including the many flavors of autonomous. In parallel with these changes, developers of simulation software have been refining their products. *DE* asked a number of these companies for their perspective on managing the complex, large-scale system designs that are rapidly becoming standard in the automotive world.



Numerical simulation of an FM antenna printed on the rear windshield of a vehicle. The far-field radiation pattern of the antenna is shown, as analyzed with COMSOL Multiphysics software. *Image courtesy of COMSOL.*

A Smartphone on Wheels

For more than 100 years, successful automotive designs have relied, for the most part, on classic engineering: Knowledge of mechanical behavior, material properties and electrical and hydraulic systems. The push for compressed design cycles slowly added computer simulations of engines, powertrains and aerodynamic responses to the required skill set, followed by increased use of multiphysics and multi-domain analyses. And yet the challenges continue to change, making us wonder: Are we even still talking about designing cars?

"The increased requirements of cars equipped with cameras, sensors, touchscreens, computers and other electronics effectively turns modern cars into large smartphones," Says Bjorn Sjodin, vice president of Product Management at COMSOL.

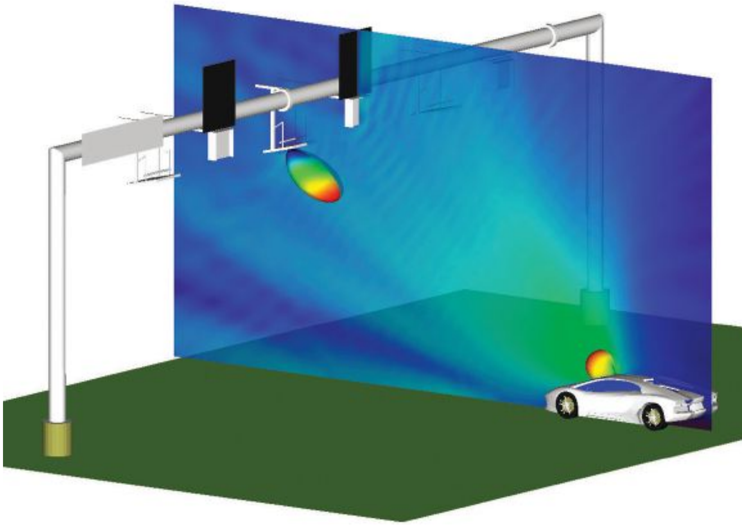
The implication, he notes, is that the automotive industry keeps getting new sets of simulation requirements, some of which are similar (or identical to) those for consumer electronics; automakers now compete with consumer-electronics companies for their workforce.

Other factors broadening the scope of automotive simulation requirements, says Sjodin, include the development of non-combustion-engine vehicles. While use of composite materials has greatly improved fuel efficiency, the push for better batteries, fuel cells, supercapacitors and wireless power transfer systems calls for a new breed of engineer experienced with electrochemistry and/or power electronics—plus the right sort of software tools .

The COMSOL Multiphysics software family addresses these needs by adding ever more simulation functions to its Application Modules, such as the RF Module that assists with simulating and analyzing rear-windshield antenna performance, and the Batteries & Fuel Cells Module that helps designers create energy-optimized cells for hybrid-electric vehicles.

With tomorrow's vehicles involving so many multiphysics, multi-domain components and systems, another simulation company, Livermore Software Technology Corporation (LSTC), is expanding its high-end simulation package LS-DYNA. This non-linear transient dynamic FEA (finite element analysis) code now offers three new multiphysics solvers that handle incompressible CFD (computational fluid dynamics), compressible CFD/chemistry and electromagnetics. Such capabilities help designers evaluate the functions of traditional-fuel, hybrid-electric or all-electric vehicle designs as well as mechanical structures, with a focus on crash-worthiness.

CAE simulations need to have a high level of predictability if CAE is to replace physical testing. Dilip Bhalsod, LSTC Michigan technical manager, says the automotive industry has been increasingly replacing physical testing with CAE simulations over the last 30 years, since the level of details in crash models have evolved to close the gap between CAE and physical testing. For LSTC, this includes developing new models for airbag deployment, ultra-high-strength steel, composite and plastic materials, spot-weld failure and other new material-joining methods employed in today's vehicles. Accurate modeling in all of these areas is the key toward virtual validation of designs and reduced design cycle time.



Near- and far-field electromagnetic antenna radiation patterns, simulating signal transmit/receive functions for a connected vehicle are pictured. *Image courtesy of ANSYS.*

With more active safety features introduced into today's vehicles, LSTC is also developing capabilities to help customers simulate and design the sensors, control systems and actuators. For simulating these complex automotive subsystems, Bhalsod sees software development in need of a new single-code philosophy. He explains: "Although most companies use a single CAD software program, downstream the piece that is consuming a lot of effort and time is the use of multi-solvers handling different disciplines like crash, NVH [noise, vibration and harshness, and] durability," he says. "There is a need for simulation software that can unify all of this." With the trend to model globalization (i.e., addressing different regulations for each country) and the desire to compress design cycles to even 12 months, such streamlining would make companies much more competitive.

> **"The increased requirements of cars equipped with cameras, sensors, touchscreens, computers and other electronics effectively turns modern cars into large smartphones."**

Dassault Systèmes, with its 3DEXPERIENCE platform, has a decades-long presence across the spectrum of automotive design, simulation and testing, and keeps expanding its offerings. Familiar technical solutions include the CATIA family of high-end 3D CAD design tools, SIMULIA Abaqus multiphysics simulation software, DELMIA products for virtual production and ENOVIA tools for global collaborative lifecycle management. Used together, these packages form a strong basis for developing tomorrow's smart and autonomous vehicles.

Functional Mock-Up Interface: The Simulation Tool We've Been Waiting For?

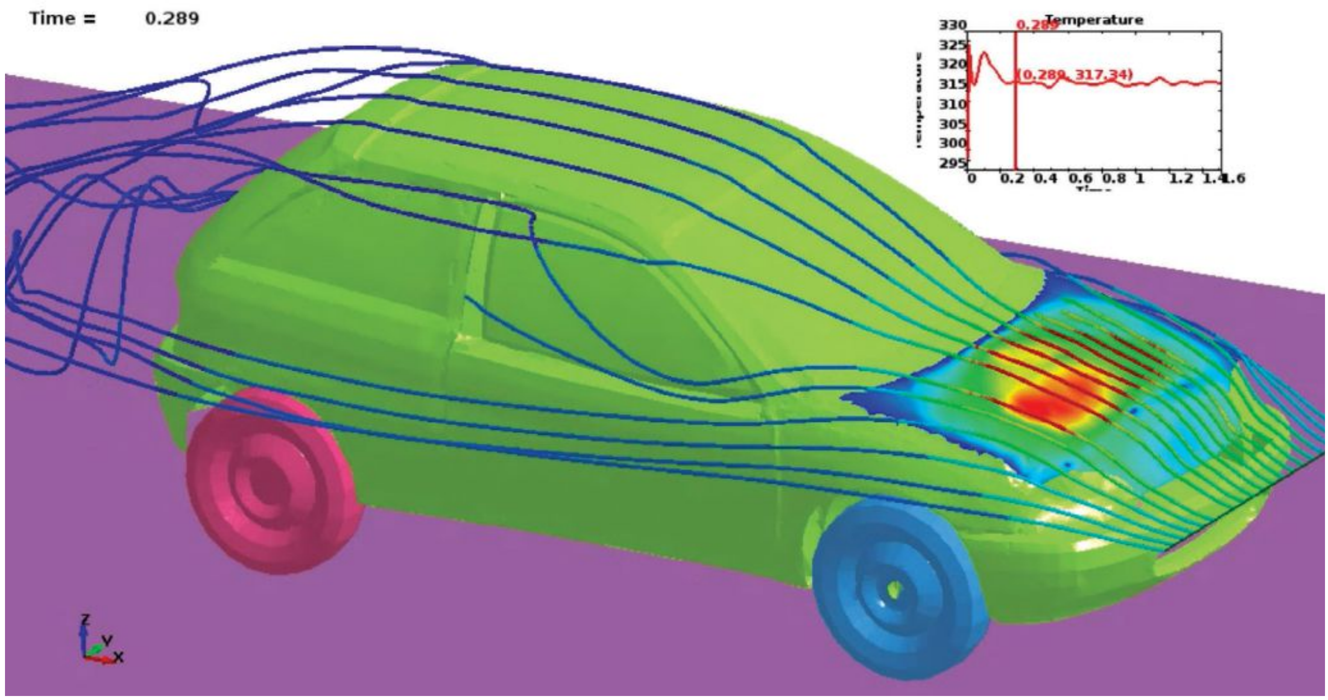
In 2008, the European Modeliser consortium began researching ways for supplier component models to be shared with OEMs, either by model import or co-simulation (coupled tools). The goal was to improve vehicle software/model/hardware-in-the-loop (HIL) simulations. The approach taken was to create an interface standard using a combination of XML files and compiled C-code. Version 1.0 of the Functional Mock-Up Interface (FMI), released in 2010, separately addressed model exchange and co-Simulation. Version 2.0, released in 2014, merged and improved both applications. The effort continues as a Modelica Association Project already comprising 90 FMI-compliant products. Altair is a member of the project advisory committee, while Dassault Systemès and Siemens PLM Software sit on the project steering committee.

– PJW

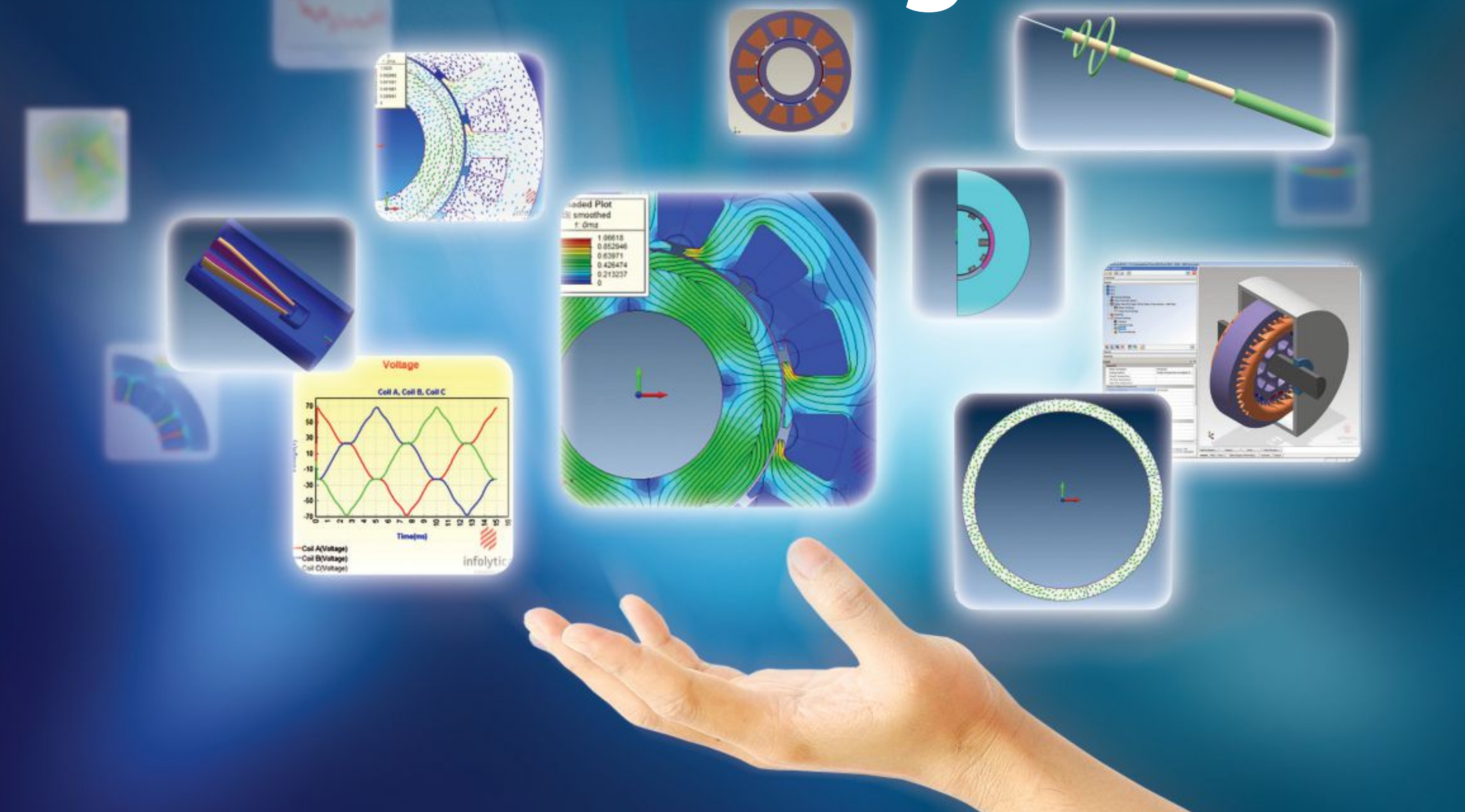
Along the way, Dassault Systèmes has recognized the value of working with model-based design technology to create optimal components, subsystems and highly connected vehicles. The company acquired Dynasim's Modelica-based modeling and simulation solutions as well as Geensoft, with its tools to generate embedded code directly from the Modelica language. (The Modelica object-oriented language lets users model complex physical systems). Then last year, it also brought on Modelon GmbH, whose multiphysics, model-based systems portfolio helps users incorporate functional mock-ups (FMUs) for electrical and mechatronic subsystem design and analysis. To offer full digital continuity from concept to compliance, Dassault Systèmes now brings these products together in what it calls the "Smart, Safe and Connected" transportation/mobility industry solution based on the 3DEXPERIENCE platform.

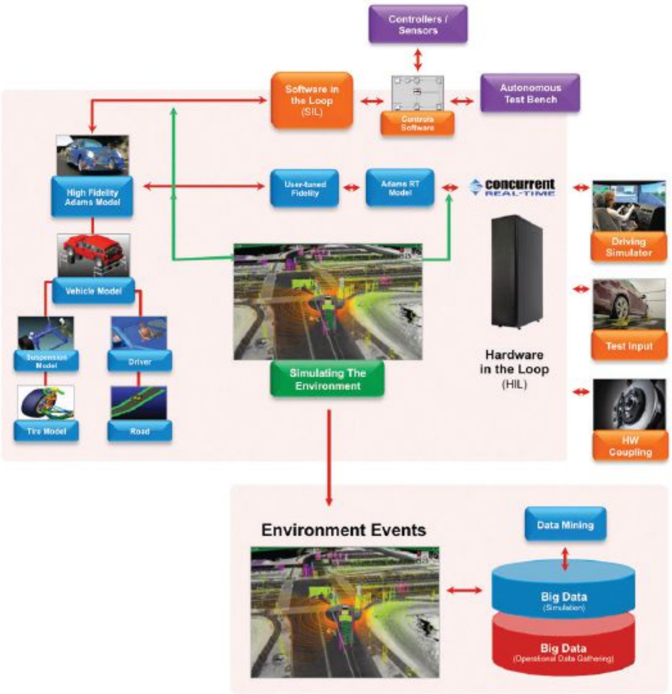
Autonomous Vehicles Moving Ahead

In the past, automotive design was all about structure and mechatronics, and design engineering companies such as Altair focused on adding innovation and optimizing geometry. Altair (through its solidThinking division) recently introduced software products that now support the full spread of concept studies, control design, system performance optimization and controller implementation/testing. Michael Hoffmann, senior vice president for Math and Systems explains this shift in thinking that supports the increasing complexity of automotive design.



Structural, thermal, CFD and radiation simulations coupled in a single LS-DYNA vehicle analysis by Livermore Software Technology Corporation (LSTC) are pictured. The process involves solving for both the temperature distribution and structural vibration of the hood. The hood is heated up by the engine but also cooled by airflow; hood vibration is due to airflow over the vehicle. ***Image courtesy of LSTC.***





Autonomous vehicle virtual process workflows can be handled by software products from MSC Software. ***Image courtesy of MSC Software.***

"We have done more than add functions," notes Hoffmann. "In solidThinking we have added three new products: Compose, Activate and Embed. In the past, Altair did not offer a lot for electrical engineering—now, with the hot topic of autonomous vehicles, the value added moves away from structures to silicon, electronics and software. We needed to address this, so the products are all based on model-based development of mechatronic systems."

Hoffmann says that the new offerings give users a number of options. "People can do conceptual modeling with abstract models, either with equations or a signal-based approach (block-diagrams), or with a physical approach like in the Modelica world," he explains. "And we want to stay longer in the game, with hardware-in-loop testing and software-in-the-loop testing—the kind of technologies that are safety-critical with autonomous vehicles."

Although the number of possible scenarios to be evaluated on such vehicles is huge, Hoffmann observes: "In simulation you can do a lot more than with actual testing. What's important is that, depending on the answers you're looking for, you can configure your simulation and easily assemble models with different types of fidelity. Activate is really central for us, so people can use this as a system simulation and integration platform, and integrate various models with various complexities." In addition, two things that customers like are being able to bring in legacy Simulink (MathWorks) models plus Altair's support of the Functional Mock-Up Interface (FMI)—the emerging standard for exchanging FMUs from different simulation environments (see "The Functional Mock-up Interface" on page 16). "It's important we provide an open environment to our users, where people can plug in their solution, using their preferred products," he says.

ANSYS also sees the big push to merge component and system simulations covering multiple domains and multiple physics, especially for autonomous vehicles. Sandeep Sovani, ANSYS director, global automotive industry, points out the complexity that this entails: "The sensory aspects of the vehicle and the processing aspects of the data, the decisions made and the actions that are taken, are all being done in a split second—therefore there is a need for all these systems to work very closely together as one unit.

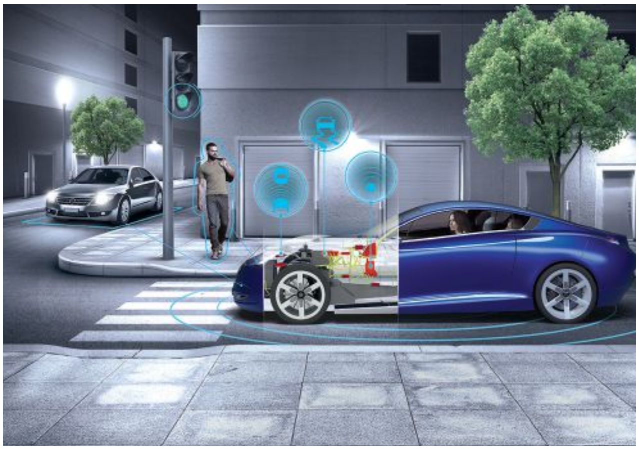
"Analogous to that," he continues, "from a simulation perspective, we need to have the ability to simulate this entire system. For now, different people are developing different things: some companies are working on sensors like radar and lidar then the OEMs (original equipment manufacturers) are developing the controller parts of them. Each of these want to simulate what inputs will come to their device, what outputs their device will give and how the rest of the system will change, based on the outputs they are given. That sets up a simulation that is essentially one giant control loop."

The level of simulation sophistication required for different parts of this platform is quite high. Sovani understands that the OEMs will not be developing this process from scratch but rather using commercial, off-the-shelf tools. This means the simulation vendors have an important role in creating the platform with the guidance of the OEMs. "This is such a large, complex field," he says, "that I envision there will be multiple players involved, with mixed tools for simulation of radar, simulation of drive-by-wire, and simulation of vehicle dynamics. The platform will need to make these disparate tools work together seamlessly (especially) for autonomous vehicles."

Where are we now? Sovani says the industry is seeing the need for such a platform, and though the technology is at the very early stage, it is maturing very quickly. He notes that Ford has announced plans to introduce SAE Level 4 autonomous cars, in which the driver has hands off the wheel and eyes off the road most of the time, by 2022.

Predict and Validate Fast

As vehicle functions have progressed from basic mechatronics to advanced driver-assistance to some fully autonomous operations, MSC Software products have also been keeping pace. For decades, OEMs and Tier One companies have been using the company's modeling and simulation capabilities for high-fidelity, off-line analyses of components and systems, handling structural analysis, noise and vibration, complex multi-body dynamics and more. "Time wise, it didn't matter if it took an hour or two to simulate a roll-over event or



Dassault Systèmes software products such as CATIA, SIMULIA and Dymola (from solution-partner Modelon) support multiphysics, multi-discipline and control-system design and simulation. ***Image courtesy of Dassault Systèmes.***

hitting a pothole. However, the move to autonomous vehicle design now requires a move to real-time processing," says Dominic Gallello, MSC Software CEO.

"What we've done for selected customers," explains Gallello, "is run our solvers on a different compute engine, on a real-time operating system. Developers don't want a reduced-order model to test against hardware—they want one continuous flow from a high-fidelity model to a model that can run in real time. This allows you to connect the virtual models to the physical hardware and validate them."

The second change Gallello observes is the explosion of data. "We have customers that run tens of thousands of simulations a month off-line of just the vehicle," he says. "But with event simulation, the amount of decision-making is monumental." (As in, what to do when the autonomous car sees a police car vs. a school bus.)

Gallello notes that MSC Software already has SimManager, a highly scalable, web-based simulation data and process management system, but he adds that it is going to have to handle many more orders of magnitude of data in capacity; putting data in, doing pattern recognition and getting it out is the go-forward task. MSC Software's strategy for this is to support connectivity, openness and emerging standards. The company has always connected natively with Simulink models, but for almost three years has also supported working with FMUs and is using them to bring data into their real-time operating system.

Through internal R&D and strategic acquisitions, Siemens PLM Software has also been building a portfolio of solutions that now address every step of smart-vehicle development. Ravi Shankar, director, Global Simulation Product Marketing at Siemens PLM, acknowledges a number of requirements that have led to the company's emphasis on highly connected, systems-level engineering: Capture and re-use of parameters from the earliest, top-level design simulations; integration of 1D system models with 3D mechanical models with control systems; collaboration across teams and suppliers; and the ability to manage design and simulation data across the product lifecycle.

All of these needs are shaping Siemens PLM Software products in support of predictive engineering analytics. The company is applying multi-discipline simulation and test, combined with intelligent reporting and data analytics, to develop digital twins that can predict the behavior of components and systems across all performance attributes throughout a product lifecycle. Its Simcenter portfolio now includes model-based LMS Imagine.Lab products, a number of 3D simulation/test capabilities such as Simcenter 3D, NX Nastran, STAR-CCM+ and LMS Virtual.Lab, the LMS testing suite, Teamcenter simulation and data process-management, and HEEDS automated design-exploration tools.

Shankar says Siemens PLM Software also supports collaboration among OEMs, Tier Ones and Tier Twos in multiple ways, with support for model-based simulations as key. "For example, Simcenter supports FMI, exporting submodels to the FMU and importing FMUs as external models for co-simulation," he explains. "On the 3D-simulation side, we offer a unique approach to the creation of finite element assemblies, which allows a distributed team to work independently while making it easy to integrate the various component models into an overall assembly." He adds that black-box approaches can be supported if details of sub-systems are to be kept proprietary.

Altair's Hoffmann neatly sums up the situation for today's automotive simulation work: "Tier One suppliers, and even Tier Two, are extremely skilled and doing as much simulation as the OEMs. What people would like is to have a continuum, where they can easily go from models that are abstract to refined to more detailed. Breaking down the silos between the different disciplines—these will be the challenges." **DE**

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INFO ➜ **Altair solidThinking:** solidThinking.com

➜ **ANSYS:** ANSYS.com

➜ **COMSOL:** COMSOL.com

➜ **Dassault Systèmes:** 3DS.com

➜ **Livermore Software Technology Corporation:** LSTC.com

➜ **Modelica:** Modelica.org

➜ **MSC Software:** MSCSoftware.com

➜ **Siemens PLM Software:** Siemens.com/PLM

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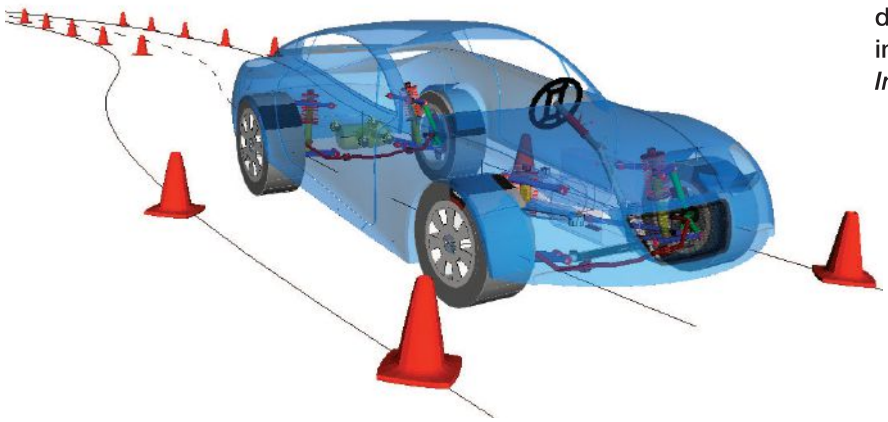


SIMULIA Simpack simulates a vehicle dynamic response to ADAS maneuvers in a 3DEXPERIENCE universe. *Image courtesy of Dassault Systèmes.*

Self-Driving Cars Test Traditional Procedures

Current physical and virtual test and simulation methods can't cover all of the possible scenarios for autonomous vehicles, opening the door to safety gaps.

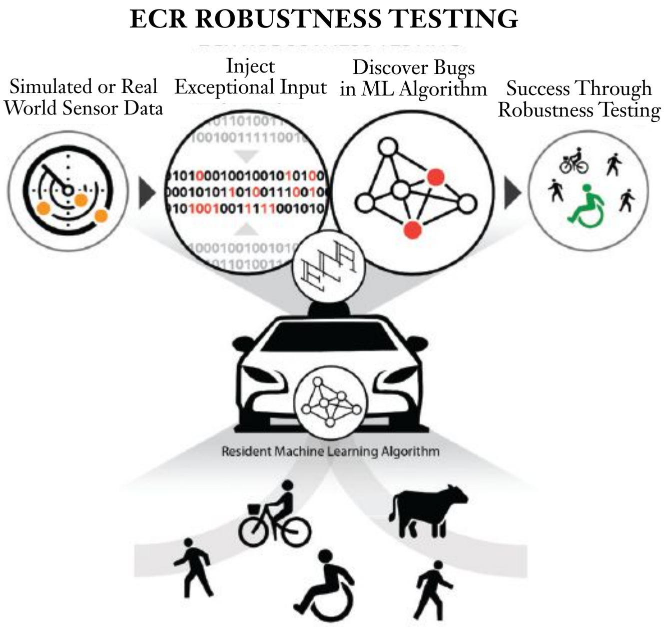
BY BETH STACKPOLE

THE SCI-FI SCENARIO OF SELF-DRIVING CARS isn't looking all that futuristic these days. Yet as big names and startups throttle up development efforts, they are also mapping out new test and validation practices to ensure autonomous vehicles can merge safely into mainstream traffic.

Early prototypes of these vehicles from automotive giants like Ford and Tesla along with tech titans like Google and Uber are already hitting city streets. Ford conducted winter weather testing of autonomous vehicles at Mcity, a full-scale simulated real-world city environment at the University of Michigan, while Google claims to have logged over 1.5 million road miles with its self-driving car project. This summer, Uber's Ford Fusion self-driving fleet took to city streets in Pittsburgh as part of a pilot to test the technology and gather feedback from customers.

The latest frenzy of development and test activity, coupled with the federal government's recent release of policies and guidelines around autonomous vehicle safety, are fueling what experts project will become a sizeable market in just a few years. By 2025, Boston Consulting Group is estimating a global market of $36 billion for partially autonomous vehicles and $6 billion for fully autonomous units.

Proponents are bullish on autonomous vehicle technology for a variety of reasons, including its ability to increase driver safety and comfort, reduce accidents, prevent traffic congestion and even cut back on emissions. For example, platooning—a type of autonomous opera-



An automated software robustness testing tool can prioritize tests most likely to unearth safety hazards for autonomous vehicles. ***Image courtesy of Edge Case Research.***

tion where a convoy of trucks is electronically linked and controlled by a lead vehicle—would save about 4% in fuel compared to separately running rigs, according to a new report from the North American Council on Freight Efficiency.

Yet for all the potential upsides, the nascent industry faces a long road ahead to get consumers comfortable with the technology, particularly as it relates to safety. A study just released by Kelley Blue Book found that just over half (51%) of respondents prefer to have full control over a vehicle, even if it's not as safe for other drivers. The unfamiliarity with autonomous vehicle technology and heightened concerns over safety is mounting pressure on industry players to ramp up and innovate more sophisticated test and validation practices beyond what's typically performed in traditional vehicle development.

"How do you really understand that the system you're putting on the road will perform over a lifespan of the vehicle and at a high enough level that will ensure you don't have catastrophes?" asks Lee Barnes, director, connected and autonomous vehicle business at global engineering consultancy Ricardo. "There's no real answer for that today."

A Holistic Test Approach

Because autonomous vehicles are considered machines, they're held to a different standard than human drivers, experts say. Moreover, the current methods of testing—real-world track tests and existing simulation practices—don't completely map to this new area of development, raising the possibility of significant safety gaps, Barnes explains. "The standard environmental testing approaches used today for testing vehicle hardware for lifelong durability and functionality are not transferable to an autonomous vehicle platform," he says. "We can still use those approaches, but we have to go beyond them for testing the system as a whole in an environment that has random situations taking place."

As part of its consulting practice in this area, Ricardo is leveraging agent-based modeling (ABM) simulation methodologies to support advanced testing and analysis of autonomous vehicle performance. The approach combines agents (vehicles, people or infrastructure) with specific behaviors (selfishness, aggression) and connects them to a defined environment (cities or test tracks) to understand the emergent behaviors during a simulation, Barnes says. The practice is used to recreate real-world driving scenarios in a virtual environment to test complex driving scenarios.

ABM and other novel forms of modeling and simulation practices are required because it's simply not possible to rack up all of the necessary physical testing miles, nor is it viable to virtually explore all of the variables when autonomous operation is involved.

Rand Corp. just released a study titled "Driving to Safety," which concluded that autonomous vehicles would have to be driven hundreds of millions of miles (sometimes even billions) to fully demonstrate their reliability in terms of fatalities and injuries. That isn't feasible

Autonomous Emergency Braking System simulation with 3DEXPERIENCE platform. ***Image courtesy of Dassault Systèmes.***

considering the industry's aggressive go-to-market timeframes, according to Nidhi Kalra, senior information scientist and the director of the Center for Decision Making Under Uncertainty at Rand.

"If we want to achieve the test driving miles necessary before making these vehicles available for consumer use, we would be waiting forever," she explains, advocating the need for alternative methods to supplement real-world testing, including well-designed pilot studies, modeling and simulation, and mathematical modeling and analysis.

ANSYS, whose simulation software is used liberally in traditional automotive testing, is working on a number of technologies to address the challenges related to simulating and testing autonomous vehicles. ANSYS is evolving its existing tools into a platform that would address simulation as a controlled loop spanning the model of the vehicle, the system of sensors sensing what is going on in the environment, the control system that interprets signals and makes decisions, and the actuator that adjusts the braking system or steering system, for example, based on vehicle dynamics, says Sandeep Sovani, ANSYS' director for the global automotive industry. The key, Sovani says, is creating a simulation platform that spans and integrates all of these aspects. "It's an integration challenge—how to move data from a scenario model into a sensor model effectively and fast," he says.

ANSYS Simplorer, a systems-level simulation tool, will play a key role, as will the work ANSYS is doing with reduced order models, an approach designed to allow highly detailed models to run in real time as opposed to taking hours or even days, he explains. ANSYS' Engineering Knowledge Management tool, which manages simulation data, will also be instrumental for integrating data across multidisciplinary simulations.

Startup Brings Simulator Capabilities to the Masses

Simulation and virtual testing is a big-ticket item for autonomous vehicle design, but one company is attempting to level the playing field by making capabilities readily accessible to startups.

The Driving Simulator and Vehicle Systems Lab, dubbed SimLab, is opening its doors in Silicon Valley, providing access to a research-grade simulator facility to startups working on advanced automotive technology. The open access driving simulation platform is made possible through a partnership with fka, an R&D spin-off of Aachen University's automotive engineering department that operates as fka SV.

SimLab, which is compliant with National Highway Traffic Safety Administration (NHTSA) guidelines, features a central vehicle with a multi-screen, 180° surround view, an immersive virtual environment to support the driver and simulation software tuned for different traffic situations. The platform is a static driving simulator, tuned to evaluate in-vehicle systems and responses to new infrastructure innovations in addition to understanding driver behavior. It's currently not aimed for testing the entirety of an autonomous vehicle in its current form.

"Most simulators are owned by OEMs (original equipment manufacturers) or labs and are not accessible by startups," says Jens Klimke, chief technology officer for fka SV. "They can come to us and we can help them set up scenarios and conduct studies, and it's quite cheap compared to other possibilities for using a simulator." —*B.S.*

Google claims to have logged over 1.5 million miles and accumulated the equivalent of over 75 years of driving experience with its self-driving car project. *Image courtesy of Google.*

Testing the Algorithms

Another big challenge involves the still nascent machine learning capabilities, which are critical for allowing autonomous vehicles to properly discern the nature of a line of sight object, but still have critical gaps in knowledge. Despite being trained to recognize a "pedestrian," the algorithms could be tripped up by someone in a wheelchair or walking with crutches, and that ambiguity can be further exacerbated by environmental conditions or sensor failures, affecting the ability to initiate a safe response. "You have the potential for millions of combinations that the algorithm may not have learned yet, and each represents a gap in the knowledge of the pedestrian detector, a software error, and a potential safety hazard," explains Michael Wagner, CEO and founder of Edge Case Research, formed by Carnegie Mellon researchers and focused on solving this very problem.

Because exhaustive testing of autonomous systems is near impossible, Edge Case Research is developing an automated software robustness testing tool code-named "free2code" that prioritizes tests that are most likely to find safety hazards. Such scalable testing tools give developers the feedback they need early in development, so that they can get on the road more quickly with safer, more robust vehicles. "What we're doing at a software level is addressing the stuff that doesn't happen often to make sure the system doesn't trip when it sees something weird," explains Philip Koopman, an associate professor of Electrical and Computer Engineering at Carnegie Mellon, who is working with Edge Case. "This kind of testing provides confidence that all the failure modes that might happen have been explored … and it's helpful to pair [the practice] with simulation testing."

Another change to typical simulation and test practices is the requirement for systems-level simulation when dealing with autonomous vehicles, notes Frédéric Merceron, Transportation & Mobility Industry Solution Experience Director at Dassault Systèmes. "Today, each functional area uses different simulation software and integrates everything together to certify that things are working well," he explains. "With an autonomous vehicle, the braking system will have some impact on other systems in the car, on the sensors or controllers. You have to have a backbone across all the different disciplines and have people working together early on multidisciplinary testing."

In addition to the 3DEXPERIENCE backbone, Dassault's Simpack, a general purpose multi-body simulation tool, and Dymola, a modeling and simulation environment based on the open Modelica language, will come into play for systems-level simulation. In addition, the recent acquisition of Computer Simulation Technology AG (CST) provides electromagnetic (EM) and electronics simulation software for simulating radars and sensors—another important component for autonomous vehicle simulation and testing. EXALEAD, Dassault's Big Data intelligence tool, will help mine data collected from the test beds and integrate it to create higher fidelity simulation models.

Ford's autonomous vehicles employ high-resolution 3D mapping and LIDAR to facilitate driving in bad conditions when road markings aren't visible. *Image courtesy of Ford.*

Given that it's early in autonomous vehicle development, many of these tools and techniques are evolving with new methods and solutions still to come. With the safety of these vehicles an imperative to their success, experts say the optimal test strategy remains a multi-pronged approach.

"There is no single way to prove their safety, but a lot of good ways to manage risk," says Rand's Kalra. **DE**

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INFO → **ANSYS:** ANSYS.com

→ **Dassault Systèmes:** 3DS.com

→ **Ford:** Ford.com

→ **Edge Case Research:** Edge-Case-Research.com

→ **fka SV.:** fka-sv.com

→ **Rand Corp.:** Rand.org

→ **Ricardo:** Ricardo.com

→ **Tesla:** Tesla.com

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Crash Simulations: More Data, Fewer Dummies

Researchers use real-world crash data, finite element simulation and supercomputing resources to take virtual crash tests to another level.

BY BRIAN ALBRIGHT

WHEN AUTOMAKERS OR SAFETY AGENCIES TEST VEHICLES, they typically rely on sensor-laden crash test dummies. However, these provide only limited information about what happens to passengers during a limited set of crash conditions. Computer models can provide much more information about injuries across a much wider variety of crash types and crash conditions. CIREN (Crash Injury Research and Engineering Network) can test thousands of variables, something that would be nearly impossible using actual vehicles and dummies because of the time and expense required, and because those crash tests generally only provide about 20 data points.

"With simulation, you get more information on the loads, stresses and strains throughout the entire human body than you would from a standard crash test dummy," says Ashley Weaver, assistant professor at the Virginia Tech-Wake Forest University Center for Injury Biomechanics. "We can predict types of organ injury or skeletal fractures on a very finite basis. The dummies may only have sensors on discrete areas of the body, so there is less information."

Weaver led a Toyota-sponsored research project at Wake Forest that used simulation and analytics to help automakers design safer cars by providing much more detailed data about what happens to passengers in a crash.

The project combined data collection with multidisciplinary analysis of medical and engineering evidence to determine how injuries occur in automobile crashes, without the expense, time, and limited data generation associated with physical crash testing. To perform these simulations, the team used a number of existing databases to recreate real-world crashes, and then vary different elements of the vehicle and passenger information to predict the types of injuries that would result from those variations. Weaver was the technology lead on the study during the second half of the five-year project.

Mining the CIREN Database

A key part of the project was the use of the National Highway Traffic Safety Administration's (NHTSA) CIREN database. The CIREN system is a computer database and wide area network for data sharing and analysis across eight trauma centers. According to NHTSA, CIREN extends its National Automotive Sampling System with medical and trauma variables in a relational/object database systems.

Engineering teams at academic engineering laboratories have been partnered with medical teams at level-one trauma centers to populate CIREN. They work together to enroll crash victims into the CIREN program. The current program includes staff at the University of Alabama at Birmingham, University of Maryland, University of Virginia, the Medical College of Wisconsin, Harborview Injury Prevention & Research Center, Virginia Tech and Wake Forest University.

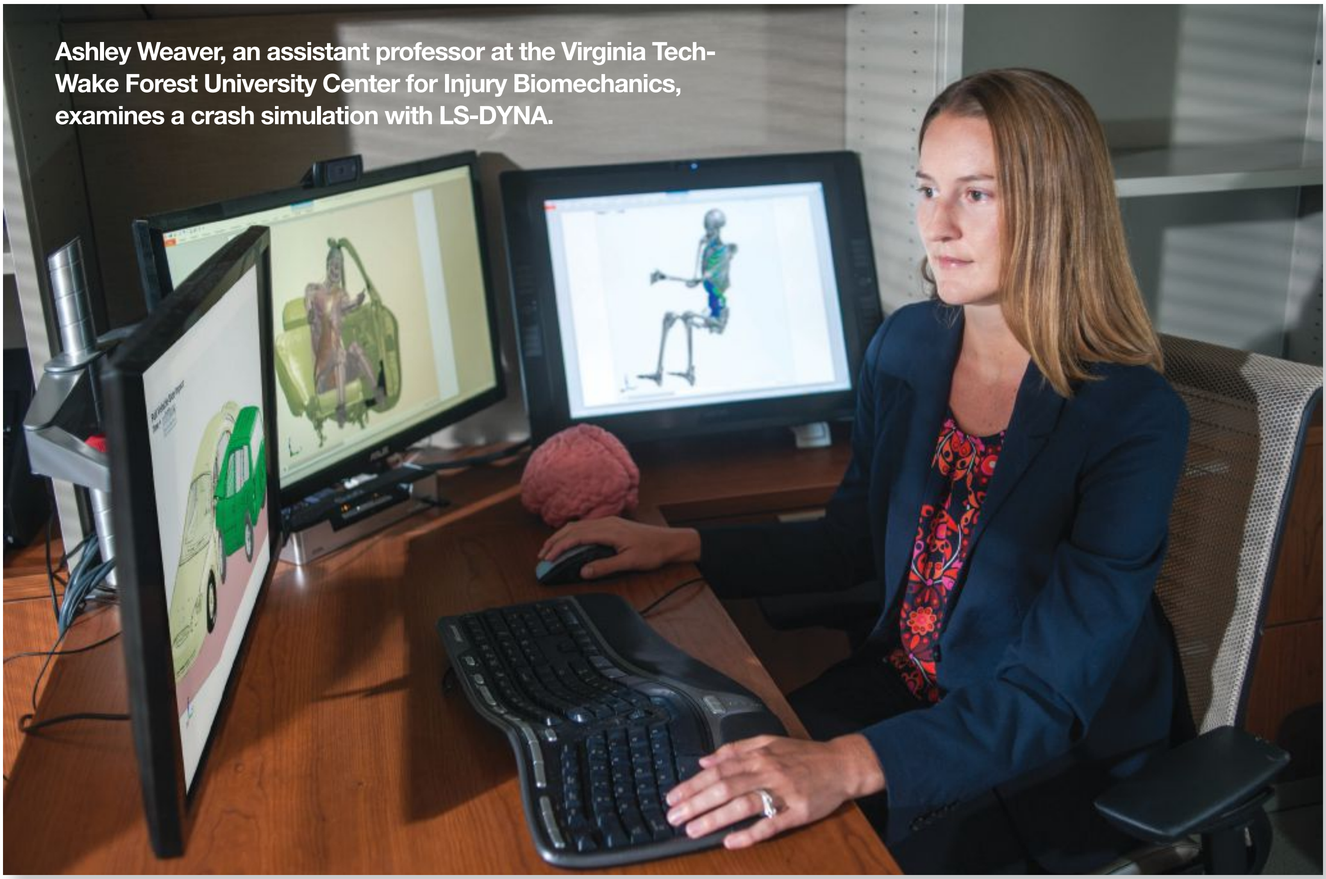
For each crash, the teams collect more than 1,000 data points on occupant injuries, vehicle damage, restraint technology and the crash environment. Both medical and engineering professionals, along with a crash investigator, review each case to determine injury causation and data accuracy.

Preparing the Models

In order to conduct the research, the team created a "tunable" vehicle model, which Weaver says was one of the primary challenges of the study. "We developed a more generic vehicle model to use with our human body model, so the characteristics of the vehicle could be tuned to represent a specific make and model. We can change the airbag or seatbelt properties, for example, to reconstruct everything from a Toyota Corolla to a Hummer," she says.

The team used Livermore Software Technology Corporation's LS-DYNA finite element code for the reconstructions, along with Toyota's Total Human Model for Safety. They used the Hybrid III ATD (anthropomorphic test device) fine element model to tune the vehicle model for the crash test experiments.

"We first tuned the vehicle model to a specific make and model, and in the second phase we took that tuned vehicle, put the Human Body Model into it and ran a set of simulations for



Ashley Weaver, an assistant professor at the Virginia Tech-Wake Forest University Center for Injury Biomechanics, examines a crash simulation with LS-DYNA.

occupant postures," Weaver says. "We also developed an injury prediction post processor, a GUI (graphical user interface) we created in MATLAB that allowed us to batch process the output from the human body model, which gave us 30 injury metrics from each of the simulations from head to toe. We could calculate injury risk from those injury metrics."

The project used crash reconstructions and crash injury data from the CIREN database and NHTSA crash test database, including detailed medical records, radiology and crash characteristics from the in-depth crash investigation records.

"We are one of six centers that enroll those CIREN cases, so we have access to the database," Weaver says. "We pulled out real-world crashes to reconstruct in the finite element environment."

Using real-world data with the simulations allowed the group to perform far more tests than would be possible with a physical crash test. "When we looked at the effect of occupant posture changes, we moved the seats forward, rearward and reclining, and looked at the changes in injury risk," Weaver says. "Instead of running 120 crash tests, we ran 120 simulations and got more information on the effects of posture on injury."

Weaver and her team used the National Science Foundation (NSF)-supported Blacklight supercomputer at the Pittsburgh Supercomputing Center and the DEAC Cluster at Wake Forest to run thousands of simulations on a virtual Toyota Camry and Chevrolet Cobalt. The Extreme Science and Engineering Discovery Environment (XSEDE) Extended Collaboration Support Service team helped set up the infrastructure and workflows to run the simulations. XSEDE is also supported by NSF.

At the time, the Blacklight system was one of the few systems that offered 1G for every compute core. The center also offered support for LS-DYNA. The team at the center helped solve some initial challenges involving job scripts for the first airbag deployment simulation that researchers worked on.

"We ended up requesting and receiving new LS-DYNA distributions that were built specifically for Blacklight," says David O'Neal, senior scientific specialist, applications development and technology support at the Pittsburgh Supercomputing Center. "We increased our license count from 100 to 250, and then 512 concurrent processes."

The Pittsburgh group also did scalability testing to help determine how to run the simulation jobs so they would be efficient. They also helped the researchers get the input data produced on an older release of LS-DYNA working with the newer version of the platform. "That's what led Livermore Software to build a special release of LS-DYNA for us," O'Neal says. "Blacklight had a vendor-specific message pathing library, so to do other types of executables we had to make special accommodations to get the older version of the software."

Simulating Crash Carnage

The researchers used the finite element simplified vehicle model and New Car Assessment Program (NCAP) crash test data to mimic the frontal crash characteristics of the CIREN case vehicles.

An additional baseline simulation was conducted to match the actual crash from the CIREN data. Validating the data involved comparing the "tuned" vehicle to the crash test data. "We took the Hybrid II element model and put it into the

CIREN used the Blacklight supercomputer located at the Pittsburgh Supercomputing Center to run its simulations. ***Image courtesy of Pittsburgh Supercomputing Center.***

generic vehicle," Weaver says. "We ran about 200 simulations of different combinations of vehicle parameters to see how well the metrics measured from the ATD finite element model matched the ATD model in the actual crash test."

The team used the vehicle parameters that best represented a particular make/model based on those matches found in the simulations. "Once we were comfortable with the accuracy of the tuned vehicle, we moved into the human body modeling phase," Weaver says.

After that, the human body model was positioned in 120 pre-crash configurations per case, changing five occupant-positioning variables. The group then did FE simulations using kinematic boundary conditions from each vehicle's event data recorder. They compared the human body model simulations to the injuries in a real-world crash case from CIREN. They used the simulations in LS-DYNA and the injury prediction post processor to generate injury metrics.

The supercomputing clusters the university used were extremely important for the research. "Both of those clusters allowed us to perform simulations very quickly," Weaver says. "We did thousands of simulations, and having access to the clusters was essential for our deadlines. We could get outputs in a few days' time for 100 simulations."

Among the findings so far: More reclined seat positions can lead to higher risk of head and chest injuries, and injury-causing stress moves from the foot to the lower leg as a driver's head comes forward into the front airbag. The simulations also allowed them to quantify the sensitivity and uncertainty of the injury risk predictions based on occupant position.

The team reconstructed 11 crashes, simulating different postures. "We found that being seated further back from the airbag in a reclining position gave us higher head accelerations and chest metrics, suggesting that the risk of head and chest injuries would be higher in a more reclined position," Weaver says. "In most physical crash tests, the dummy is in the same position. We wouldn't know the effect of recline without doing those simulations."

Weaver says that physical crash testing does have some advantages in that experiments have to be run to verify the computer models, but "the advantage of computer modeling is still that you can run more simulations at a much lower cost," she says.

Making Cars Safer

Toyota, which sponsored the study, has been able to access the data and findings to use in its own vehicle design. According to Weaver, additional automakers and other researchers are interested in using the tunable generic vehicle model developed for the study as well, in addition to the injury prediction post processor.

"For automakers, this can provide them with a way to vary the different properties of the vehicle, such as the properties of a seatbelt or the vent area on an airbag, during development," Weaver says. "Our findings on changes in occupant posture and position and the change injury metrics could play into those design decisions."

The researchers have additional proposals out to use the modeling methodology developed for the study to extend their work. "One area we are interested in is active safety and doing simulations on that technology, and how injury risk can be affected by having active braking systems, for example," Weaver says. "We could evaluate in the simulation what the reduction in injury risk could be if active braking were in place, vs. the result without it across different vehicle designs." Another potential research topic: Occupant positioning in autonomous driving vehicles.

For automotive engineers, the modeling developed for this study can provide a way to validate new safety features and determine injury risk across multiple crash variables—and do so in a way that is much faster, more detailed and more affordable than physical crash tests or using hypothetical crash data. **DE**

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INFO → **CIREN:** NHTSA.gov/Research/Crash-Injury-Research-(CIREN)

→ **Livermore Software Technology Corp. (LSTC):** LSTC.com

→ **NHTSA:** NHTSA.gov

→ **Pittsburgh Supercomputing Center:** PSC.edu

→ **Virginia Tech-Wake Forest University Center for Injury Biomechanics:** CIB.VT.edu

→ **Wake Forest University:** WFU.edu

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What's Happening to Cluster Computing?

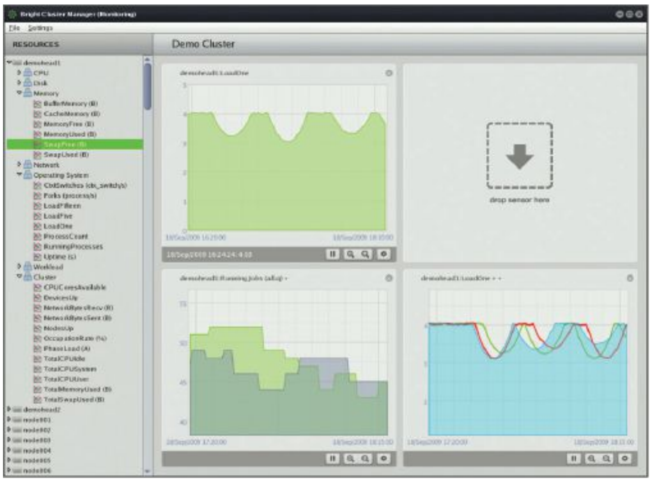
The cloud is changing how engineering teams access and accelerate high-performance computing power.

BY RANDALL S. NEWTON

IN 1980, A HIGH-END COMPUTER FOR DEMANDING ENGINEERING projects could be described by the three Ms: 1 million instructions per second, 1 million bytes of memory and 1 million pixels for graphics. In 2016, the average smartphone surpasses those numbers by wide margins. The computing power we once saw as high-end is now a commodity.

In recent years, engineering firms have maximized their ever-increasing need for computational performance by using cluster technology that links together multiple servers to work as one logical unit for high-performance applications including simulation and analysis. Advances in software services like virtualization and server grids make it easier for engineering companies to expand their existing clusters to serve growing internal demand. Prices dropped and power increased for years. Many computers known as supercomputers today are just very large clusters.

What we call cloud computing today is rentable time on a massive array of servers, available on demand from any location. Cloud technology is moving to the forefront, offering computing as a utility, not an infrastructure investment. This new wave of computing raises new questions: What happens to on-site cluster computing? Is the democratization of local resources ending with the move to off-site cloud? What happens to existing high-performance computing (HPC) installations?



Bright Computing reduces cluster management—including extending the cluster onto a cloud infrastructure—to a desktop dashboard. ***Image courtesy of Bright Computing.***

Democratized HPC as the New Normal

The evolution of computer power is a story of standardization, not differentiation. From proprietary minicomputers to RISC/Unix workstations to x06 PCs, the price/performance ratio continues to favor commodity products. When hardware commoditizes, software follows with standardization. Today's web is built on an open-source software stack of Linux, Apache, MySQL and PHP. A similar stack is evolving for using clusters in HPC using the new OpenHPC, an open source software project seeking to assemble an integrated collection of HPC-centric software/middleware components. Combined with efforts from leading HPC hardware and services vendors like Dell EMC, HP Enterprise and IBM, the day is getting closer when the average enterprise or the typical engineering department will consider supercomputer capabilities as typical as running a web server or a PLM (product lifecycle management) installation is today.

But where will those supercomputer capabilities reside? On-premise as an upgraded cluster, or off-premise in a cloud? The answer: "All of the above and more." Software developers are coming up with technologies to repurpose existing clusters, help on-site clusters work in a cooperative fashion with off-site cloud services and provide the key capabilities of cloud in a private setting. The same scalability and accessibility can be provided on a smaller scale by existing clusters.

Containers for Shipping Software Packages

UberCloud is a company with a big mission: To democratize the HPC experience so that clusters, grids and clouds all become one happy computational family. Their business model is to combine elements of the open-source community ethic of shared resources and open development, with a commercial set of features to create what they call "computing-as-a-service."

UberCloud delivers engineering services ready to execute out of the box using what they call container technology. The container metaphor draws on how standardized containers revolutionized the intercontinental shipping industry in '80s. The containers are available for many of the most popular engineering products, including several ANSYS products; Siemens PLM Software's CD-adapco Star-CCM+ and Red Cedar HEEDS; COMSOL Multiphysics; Nice DCV; Dassault Systemès SIMULIA Abaqus; Numeca FINE/Marine and FINE/Turbo; OpenFOAM and others. Customers are using UberCloud containers to run these products on cloud resources from Advania, Amazon, CPU 24/7, Microsoft Azure, Nephoscale and OzenCloud.

UberCloud says its container approach eliminates the need for a hypervisor to manage virtual machines. They also claim near-bare-metal results for engineering applications. "When we came across UberCloud's new application container technology and containerized all our CFD software packages, we were surprised about the ease of use and access to any computing system on demand," says Charles Hirsch, founder of Numeca.

Any service where multiple CPUs and servers are running as a unit looks like a cloud to UberCloud.

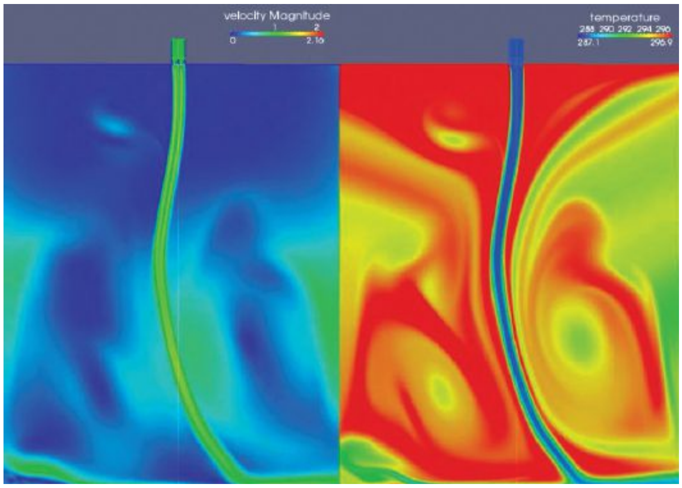
Simplifying Clusters

"Clustering is hard," says Bill Wagner, CEO of Bright Computing. "Talk to anyone who has done it. It is difficult to build a cluster; it is difficult to manage it over time; it is difficult to monitor it." Bright Computing brings a dashboard approach to cluster deployment and management, and claims their software can take a client from bare metal to deployment in under an hour.

One advantage Bright Computing brings to managing clusters is the ability to "cloud burst" any application running in the Bright environment. This dynamically extends the use of CPUs beyond the premises to either a private or public cloud, as needed.

The Institute of Aircraft Design at the University of Stuttgart is a Bright Computing customer. Routine IT requirements are handled by university IT, but the institute runs its own cluster for research. Its most demanding simulations were taking weeks to run. When the open-source cluster manager OSCAR failed to work with upgraded cluster hardware, the institute tested Bright Cluster Manager. "Upgrades that used to take us weeks to complete can now be done in a few days," says Alexander Schon, a member of the institute's technical staff. "It is very user friendly and greatly reduces the time necessary for managing a cluster."

OpenStack is an open-source framework for turning clusters into private clouds, but no one will tell you it is easy to use. Bright Computing has a special edition of Cluster Manager fine-tuned



Biscari Consultoria tested UberCloud for running a highly coupled computational fluid dynamics simulation using Amazon Web Services as an alternative to extending an existing in-house cluster. *Image courtesy of UberCloud.*

for the OpenStack environment. It is part of Bright Computing's cluster-as-a-service initiative, which now offers a management framework for HPC and Hadoop systems as well as OpenStack deployments. When a temporary extension to one of these environments is required for a project, Cluster Manager can open up new cluster resources as the desired system. The result: A cloud-like extended deployment behind the firewall or beyond into a public cloud setting as required.

Building Commodity Supercomputers

Hardware vendors are still selling servers for deployment in clusters, but the focus has changed from the CPU to the total infrastructure. Dell EMC and HP Enterprise both offer a variety of services for cluster deployment and management, and have partnerships with the software vendors already mentioned here.

The goal of all these efforts is commodity supercomputing. Engineering companies are not ready to toss out their existing infrastructure for cloud computing without practical results. Empowering existing cluster resources with easier deployment, greater ease of use and the ability to extend onto a public or private cloud as needed gives new life to clusters. Cluster commoditization via software innovation does not eliminate the need for clusters, but instead increases their utility for engineering.

This new emphasis on ubiquitous computing resources achieved through software makes it easier to adjust to changes. UberCloud, Bright Computing and others are making every computer in reach a node on the existing cluster network, up to and including the thousands of CPUs available on demand from public cloud services. **DE**

Randall S. Newton *is principal analyst at Consilia Vektor, and a contributing analyst for Jon Peddie Research. He has been part of the computer graphics industry, in a variety of roles, since 1985.*

INFO ➜ Bright Computing: BrightComputing.com

➜ UberCloud: TheUberCloud.com

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HPC Workflow Tips

Technology offers a pathway to better product design and development.

BY JIM ROMEO

TODAY'S DESIGN ENVIRONMENT has many new and emerging tools to help design engineers capitalize on a voluminous amount of data to design and build better products. One tool that brings many benefits is high-performance computing (HPC) and its ability to speed workflows.

Supercomputers and parallel processing techniques are at the center of an HPC workflow. They enable organizations to solve complex computational problems in less time, and visualize and predict things before they implement design solutions and ideas.

View and Predict Before the Build

"One common aspect to most HPC workflows is the notion of forward view, or prediction," says Eric Polet, Emerging Markets program manager at Spectra Logic. "HPC systems are used to predict weather, climate, atomic reaction and more, so when developing a product, it allows you to view and predict the outcome of a system prior to going to a physical environment.

"As an example, let's assume we are building an engine for a car," Polet continues. "One key component of that engine would be the cylinder head. The cylinder head provides power to the engine and the emissions that will be put out by the engine. By simulating the cylinder head and the engine through a computer prior to going to tooling, an engineer can tweak parts and get the best performance with the lowest emissions."

Polet posits that HPC enables processing of vast amounts of information to provide granular detail used to drive decisions for successful outcomes. Without HPC, a trial and error approach, or as he describes it "tribal knowledge" on engine combustion would be used.

"This same type of simulation is used for weather, climate and pandemic sciences that need a future view," Polet adds. "As organizations implement a product development workflow, it is vital to confirm their infrastructure can grow with their organization, ensuring resources are maximized not just today, but for years to come. Regardless of when and how often data is read, it is vital that organizations have a reliable and affordable archive where data can be stored for future analysis and recalled whenever needed."

Not long ago, HPC required more IT infrastructure. Large mainframe computers at colleges and universities were commonly used. Today, things are simpler.

For today's engineer, HPC is much easier and more hassle-free than in the past—especially with on-demand, high-performance cloud services.

"They no longer have to wait for queued simulation jobs to run, or write complex scripts to do work," says says Leo Reiter, CTO at Nimbix, an HPC cloud platform provider. "Modern platforms provide turnkey workflows for the simulation applications they're using, but with a much larger scale than they may be used to. This means they can get their work done much faster, without learning new methodologies first, and at very economic prices without upfront commitments."

HPC Product Development

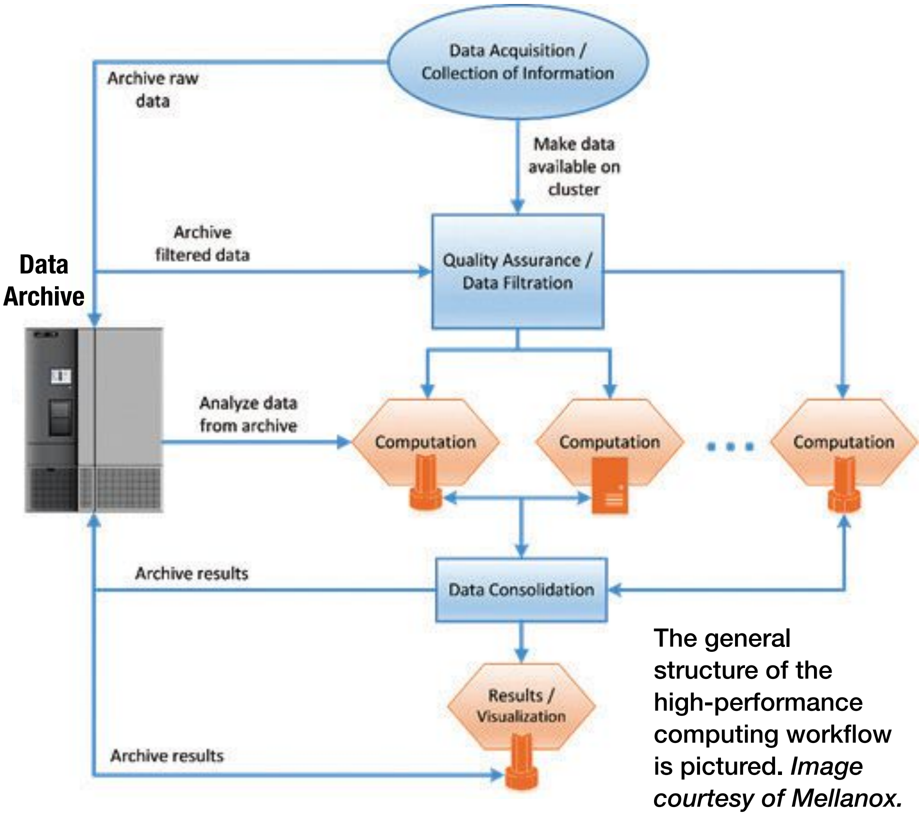
Structuring a logical workflow to accommodate the processing requirements of their project is one challenge engineers face in utilizing HPC.

"Depending on the type of product, it's best to identify which steps of the workflow actually require HPC, and take into account where data needs to be available at any given time," says Reiter. "For example, for a typical manufacturing process, there is design, simulation and post processing. Typically, only simulation is the stage of the workflow that actually requires HPC. But if the data sets are large enough, it's important that the data be near-line to each stage. For example, if leveraging cloud computing for HPC, it's important that the cloud support all three steps of the workflow so that you don't need to move data back and forth as part of the workflow. It's also important that the platform support batch processing for the HPC parts so that you are not paying for setup and tear down time and effort as well."

According to Scot Schultz, an HPC technology specialist at Mellanox, it's best to apply boundaries to the applications required for the product development, and then look at the number of elements, network communication patterns and access to storage commonality for the application.

Building a network that allows HPC workflow and function is key, and achieving this often means removing clutter from the flow.

"For operations like Message Passing Interface (MPI), it's best to manage this from the fabric, not the CPU," says Schultz. "It really starts with one very basic idea—remove overhead that is not fundamental to a core element, and then, if possible, optimize and accelerate it. In other words, CPUs should be doing compute;



The general structure of the high-performance computing workflow is pictured. *Image courtesy of Mellanox.*

not managing network communication—the network should be intelligent and powerful enough to handle the network functions needed across the I/O and the compute. Very similar for storage—leveraging native Remote Direct Memory Access (RDMA) storage can make the difference in a workflow's time-to-solution."

Data Size Matters

Attention should be directed to several areas when developing an HPC workflow. One of these areas is the size of your data set and what kind of cloud configuration will work best and easiest for that size.

Organizations that are best suited for public cloud and SaaS (Software-as-a-Service) are those with smaller data sets and low data analytics needs. With a pay-as-you-go, or subscription model, a public cloud is a more affordable option for storing, analyzing and sharing data. Paired with minimal startup costs and hardware needs, organizations can implement a full public cloud environment while meeting all necessary requirements. However, this changes as the data set grows.

"As data sets grow, and demand for data analytics increases, organizations find themselves moving to clustered file systems, located on premise," says Polet. "These clustered systems provide almost infinite computing power, but with additional power comes added costs. For organizations utilizing clustered file systems, cloud computing and storage would be a far more expensive option, due to the amount of virtual machines that would be needed to perform in the cloud. Clustered systems have limitations in affordable storage capacity and ability to distribute data, which are important to factor into decisions. However, for organizations needing high data analytics, small data archives and limited distribution of content, a clustered system is ideal and the most affordable."

For those with larger data sets where analytics and computation is more involved, a data center with large amounts of storage and substantial compute power to analyze their data is in order.

"If one of these organizations were to go to a fully public cloud infrastructure, the costs would be so enormous they may have to choose what data to keep and what computations to run," says Polet. "With a clustered system, storage would be limited and the organization would have to decide what results to retain and what data is important. One limitation to data centers, as opposed to cloud, is the inability to share and distribute data. Often times, organizations are required to introduce additional hardware and software to perform these tasks. The benefits of a data center, however, are that organizations are able to store all their data, keep it for as long as they need and perform the required computations."

Making HPC Work

HPC has come a long way. With the right workflow, it can be a game changer for today's design engineering teams. Getting work done faster translates to savings and provides an attractive return on your investment in HPC.

"Remember the old adage, time is money?" asks Scott E. Grabow, HPC system administrator for BAE Systems' Intelligence and Security sector. "HPC can potentially give you more time to use the knowledge you develop than a competitor. In terms of a product development cycle, that could mean you get a shorter product design cycle. You can take advantage of that cycle to improve quality, performance or give you a longer period of time to generate and drive the media buzz to your product. Your decisions can allow you to gain a larger market share than your competition by allowing you to sustain the conversation with your product." DE

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Jim Romeo (*JimRomeo.net*) *is a freelance writer based in Chesapeake, Virginia.*

INFO ➜ **BAE Systems:** BAESystems.com

➜ **Mellanox:** Mellanox.com

➜ **Nimbix:** Nimbix.com

➜ **Spectra Logic:** SpectraLogic.com

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Affordable CAD Performance

The entry-level Dell Precision 3620 Mini Tower workstation delivers very good performance for its price.

BY DAVID COHN

The Dell Precision 3620 mini tower features a new look and very good performance for an entry-level system. The rear panel provides lots of connections. *Images courtesy of Dell.*

While we have recently written about Dell's newest mobile systems, it has been nearly five years since we last reviewed a Dell Precision tower workstation. We were therefore pleased when the company sent us its latest entry-level workstation, the Dell Precision 3620 Mini Tower. According to Dell, this latest update to its Tower 3000 series is 33% faster than its previous generation in terms of CPU, graphics and memory. With that claim in mind, we couldn't wait to put the Precision 3620 through its paces.

The updated 3000 series desktop workstations are actually available in two different formats, both as a mini-tower (the 3620 we received) and as a small form factor (designated 3420). The 3620 has a starting price of $629 while the 3620 starts at $649. At that price, you get a dual-core 3.7GHz Intel i3 processor, 4GB of RAM and a 500GB 7200rpm hard drive, but must rely solely on the graphics capabilities integrated into the Intel CPU. Even entry-level CAD users will likely need more memory and want better graphics than the base-level offering.

With its redesign, the Dell Precision 3620 looks nothing like its predecessors. Gone is the sculpted silver front. All Dell Precision towers now have a very rectilinear appearance. The system we received measured 6.87x17.87x14.25 in. (WxDxH) and tipped the scales at just 19 lbs. The plastic front bezel is divided into three distinct zones: A top portion providing front-panel access to two 5.25-in. drive bays, a narrow vertical band containing audio jacks and USB ports, and a recessed grille for air intake. The lip of that recess, along with another recess in the rear panel, serves as handles for carrying the workstation.

On our evaluation unit, one of the front bays came filled with a 16x DVD +/-RW drive while the narrow vertical band contained microphone and headphone jacks, two USB 3.0 ports, and a pair of USB 2.0 ports. The small rectangular power button was nearly hidden in the upper-left corner of the front bezel.

The rear panel hosts a 9-pin serial port, four more USB 3.0 ports, two additional USB 2.0 ports, PS/2 keyboard and mouse ports, an RJ-45 connector for the integrated gigabit network, two more audio jacks, and both an HDMI connector and a pair of DisplayPorts for the graphics integrated into the Intel CPU.

Lots of Room Inside

Unlike older Dell Precision workstations, the new 3620 case opens on the left and the interior is quite spacious. A 3.5-in. drive cage hangs below the 5.25-in. front panel drive bays. There are also two additional 3.5-in. drive bays in the bottom-front corner of the case.

The motherboard, based on an Intel C236 chipset, provides four DIMM (dual in-line memory module) slots for up to 64GB of 2133MHz memory. It also includes four full height expansion slots—one PCIe x16 Gen 3 slot, a second PCIe x16 Gen 3 slot wired as x4, a PCIe x4 Gen 3 slot, and a single PCI slot—as well as provision for a single M.2 device.

While the company offers a choice of 10 different CPUs, Dell equipped our evaluation unit with the most powerful option, an Intel Core i7-6700K, a 4.0GHz quad-core CPU with 8MB cache, a maximum turbo frequency of 4.2GHz, and a thermal design power (TDP) rating of 91 watts. Our evaluation unit also came with 32GB of non-ECC RAM, installed as four 8GB modules.

In addition to the integrated Intel graphics, Dell also offers a choice of 12 different discrete graphics cards from AMD and NVIDIA. Again, our system came with the most powerful offering, an NVIDIA Quadro M4000 installed in the PCIe x16 slot. This GPU (graphics processing unit), based on NVIDIA's Maxwell architecture, comes with 8GB of GDDR5 memory and 1644 CUDA (compute unified device architecture) cores. The board provides four DisplayPorts and supports display resolutions up to 4096x2160 at 60Hz. Although it consumes just a single slot, its 120-watt power

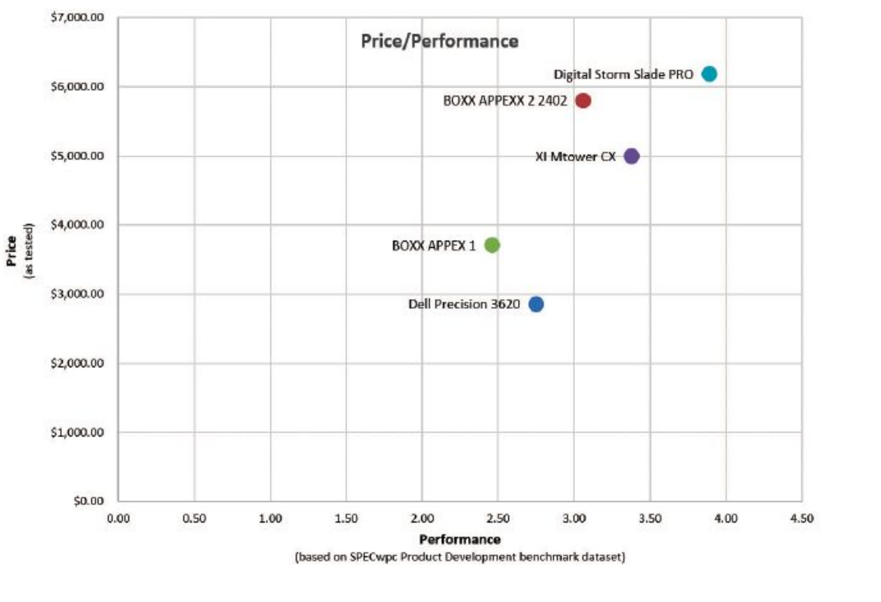
Single Socket Workstations Compared	**Dell Precision 3620** one 4.0GHz Intel Core i7-6700K 4-core CPU, NVIDIA Quadro M4000, 32GB RAM, 512GB PCIe SSD and two 1TB SATA drives in RAID 0 array	**BOXX APEXX 2 2402** one 4.0GHz Intel Core i7-6700K 4-core CPU over-clocked to 4.4GHz, NVIDIA Quadro M5000, 16GB RAM, 800GB PCIe SSD	**BOXX APEXX 1** one 4.0GHz Intel Core i7-6700K 4-core CPU over-clocked to 4.4GHz, NVIDIA Quadro K1200, 16GB RAM, 512GB PCIe SSD	**Xi Mtower CX** one 3.0GHz Intel Xeon E5-1660 v3 8-core CPU over-clocked to 4.1GHz, NVIDIA Quadro M5000, 16GB RAM, 256GB PCIe SSD and 1TB SATA HD	**Digital Storm Slade PRO** one 3.1GHz Intel Xeon E5-2687W v3 10-core CPU, NVIDIA Quadro M4000, 32GB RAM, 400GB PCIe SSD and 2TB SATA HD
Price as tested	$2,860	$5,806	$3.711	$4,997	$6,187
Date tested	8/5/16	1/30/16	1/30/16	1/25/16	10/18/15
Operating System	Windows 10	Windows 10	Windows 10	Windows 10	Windows 10
SPECviewperf 12 (higher is better)					
catia-04	86.07	133.05	34.95	126.16	78.54
creo-01	72.47	108.03	33.45	107.44	65.60
energy-01	6.33	11.44	2.56	11.65	6.31
maya-04	69.94	101.53	31.22	97.68	63.79
medical-01	26.54	45.12	11.41	45.78	25.99
showcase-01	45.77	60.37	18.99	61.65	42.26
snx-02	72.93	121.01	28.47	219.48	74.62
sw-03	108.73	158.22	70.56	149.88	110.74
SPECapc SOLIDWORKS 2015 (higher is better)					
Graphics Composite	8.23	7.65	5.17	5.89	n/a
Shaded Graphics Sub-Composite	4.95	4.19	2.86	3.16	n/a
Shaded w/Edges Graphics Sub-Composite	6.36	5.57	3.92	4.22	n/a
Shaded using RealView Sub-Composite	6.35	5.45	3.56	4.32	n/a
Shaded w/Edges using RealView Sub-Composite	10.19	9.01	6.17	7.20	n/a
Shaded using RealView and Shadows Sub-Composite	7.07	6.77	4.15	4.97	n/a
Shaded with Edges using RealView and Shadows Graphics Sub-Composite	10.57	10.29	7.20	7.67	n/a
Shaded using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	15.04	14.87	7.78	11.94	n/a
Shaded with Edges using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	21.89	21.17	11.63	17.69	n/a
Wireframe Graphics Sub-Composite	3.88	4.19	4.17	2.98	n/a
CPU Composite	4.96	6.09	6.75	5.87	n/a
SPECwpc v2.0 (higher is better)					
Media and Entertainment	3.22	3.52	2.84	3.84	3.67
Product Development	2.75	3.06	2.46	3.38	3.89
Life Sciences	3.25	3.65	2.96	4.19	4.46
Financial Services	1.40	1.54	1.53	2.59	2.55
Energy	2.77	3.17	2.70	4.37	4.57
General Operations	1.58	1.99	1.93	1.78	1.47
Time					
Autodesk Render Test (in seconds, lower is better)	58.20	41.70	46.30	25.30	47.33

Numbers in blue indicate best recorded results. Numbers in red indicate worst recorded results.

consumption means that auxiliary power is required. Choosing that board also meant that our system had to be equipped with a larger 365 watt 90% efficient power supply in lieu of the 290 watt 85% power supply included in the base price.

The graphics board is held in place with a plastic bracket secured by several screws. This bracket blocks access to both the expansion and memory slots, and would need to be removed in order to change memory or add additional options.

Dell also equipped our evaluation unit with much more robust hard drives: a 512GB M.2 PCIe solid-state drive (SSD) as the boot drive and a pair of 1TB 2.5-on. SATA 7200rpm drives installed in the internal drive bays and configured as a RAID 0 array for storing data. We do not advocate RAID 0, however. Because the two mechanical drives appear as a single 2TB drive, the failure of either drive would result in data loss. System cooling is provided by a single 3-in. fan on the rear panel in addition to the fan on the graphics board and the one in the power supply. The system ran cool and quiet, maintaining a consistent 35dB sound level (compared to 29dB background noise) throughout our tests.



Great SOLIDWORKS Performance

The Dell Precision 3620 turned in very good performance for an entry-level system, but certainly did not set any records. On the SPECviewperf tests, its graphics results placed it squarely in the middle of the pack, although it was much faster than the entry-level systems we tested a few years ago. On the SOLIDWORKS test, however, the Precision 3620 actually out-performed all of the other systems we have tested to date, including some costing twice as much.

On the very demanding SPECwpc benchmark, the Dell Precision 3620 also turned in very good results, even garnering top scores on some portions of this test, although it also came in last on others. Its average time of 58.20 seconds on our AutoCAD rendering test, however, was closer to what we now expect from mobile workstations, and placed the Dell Precision 3620 at the bottom of the list of recently tested towers.

The Dell Precision 3620 is backed by Dell's standard three-year warranty with onsite/in-home service after remote diagnosis. Dell also offers data protection and additional hardware support services for up to five years for an additional fee. Dell rounded out our evaluation unit with a 3-button optical mouse and a decent 105-key keyboard.

As configured, the system we received cost $2,860. At that price, the Dell Precision 3620 is an excellent choice as an entry-level to mid-range CAD workstation. **DE**

David Cohn *is the senior content manager at 4D Technologies. He also does consulting and technical writing from his home in Bellingham, WA and has been benchmarking PCs since 1984. He's 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 dscohn.com.*

INFO ➜ Dell: Dell.com

Dell Precision 3620 Mini Tower

- **Price:** $2,860 as tested ($649 base price)
- **Size:** 6.87x17.87x14.25 in. (WxDxH) mini tower
- **Weight:** 19 lbs.
- **CPU:** 4.0GHz Intel Core i7-6700K quad-core w/ 8MB cache
- **Memory:** 32GB DDR4 at 2133MHz
- **Graphics:** NVIDIA Quadro M4000 w/ 8GB memory and 1644 CUDA cores
- **Hard Disk:** One 512GB M.2 PCIe 3.0 SSD, two 1TB 2.5-in. SATA 7200rpm drives configured in a RAID 0 array (for a total drive size of 2TB)
- **Optical:** One 16X DVD+/-RW
- **Audio:** Integrated 2-channel Realtek ALC3861 High Definition audio codec (microphone, headphone, line-in, and line-out)
- **Network:** Integrated Intel 10/100/1000 LAN
- **Other:** One 9-pin serial, six USB 3.0 (2 front/4 rear), five USB 2.0 (2 front/2 rear/1 internal), two PS/2, two DisplayPort, one HDMI
- **Keyboard:** 105-key Dell wired keyboard
- **Pointing device:** Dell wired mouse

Desktop-Worthy

The powerful Xi PowerGo XT mobile workstation delivers desktop performance.

BY DAVID COHN

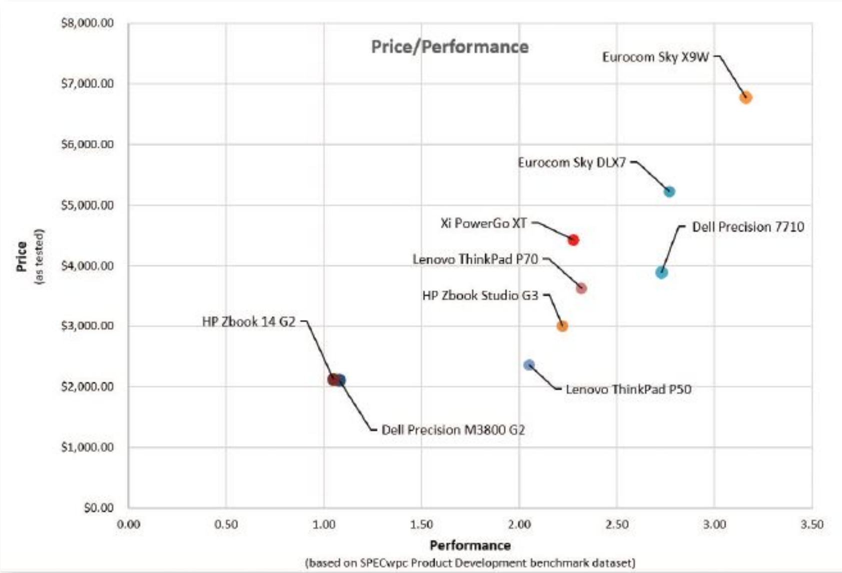
The Xi PowerGo XT mobile workstation.
Image courtesy of @Xi Computer.

WHILE WE HAVE REVIEWED SEVERAL WORKSTATIONS from California-based @Xi Computer Corporation (pronounced "at-ex-eye") in the past, the Xi PowerGo XT that recently arrived in our office marks the first mobile workstation the company has ever sent us. Billed as a high-end portable aimed at 3D modeling and simulation, we were quite excited to put this system through its paces.

The PowerGo XT is similar to several other systems we've recently reviewed. Based on an Intel Z170 Express Skylake chipset, @Xi actually offers the system in both 15.6-in. and 17.3-in. configurations, with screens providing either 1920x1080 HD or 3840x2160 FQHD resolutions. The advertised base price of $1,679 is for the smaller version with the HD display, a 3.3GHz Intel Core i5-6600 quad core CPU, 8GB of 2133MHz RAM, an NVIDIA Quadro M1000M GPU (graphics processing unit), a 500GB 5400rpm SATA hard drive, built-in gigabit LAN and Windows 10 Home 64-bit.

The 17.3-in. laptop we received came housed in a sculpted charcoal gray case measuring 16.46x11.10x1.52 in. and weighing 8.38 lbs. Its large 230-watt power supply (7.06x3.43x1.37 in.) adds another 2.3 lbs., bringing the total system weight to nearly 11 lbs.

Raising the lid reveals the display and a very good backlit 102-key keyboard and numeric keypad. A 4.25x2.4 in. gesture-enabled touchpad with a pair of buttons and fingerprint reader are centered below the spacebar. Centered above the display is a 2-megapixel webcam and microphone array. There is also a pair of speakers for the built-in Sound Blaster X-Fi MB5 sound system located in a raised perforated panel in line with the hinge, with a subwoofer on the bottom of the case. A small panel in front of this contains the power button, flanked by LEDs



for airplane mode and hard drive activity lights on the left and caps lock, scroll lock and number lock on the right. And as we have seen in other similar systems, you can control the intensity of the keyboard backlighting using function key combinations or open a special utility program to change the backlight color and lighting effects as well as program hotkey combinations to launch other programs.

A Wealth of Options

The right side of the case offers a single USB 3.0 port; an S/PDIF-out jack; audio ports for headphone, microphone and line-in, and a security lock slot. The left side provides an RJ-45 network port, two additional USB 3.0 ports, a USB 3.1 (Type C) Thunderbolt 3 port, a 6-in-1 SD card reader and a combined eSATA/USB 3.0 port that remains powered for recharging devices even when the system is off (as long as the computer is connected to a working A/C outlet). The rear panel hosts a single HDMI port, two DisplayPorts, and the connection for the external power supply, flanked by a pair of air vents. There are many additional air vents on the bottom of the case. There is no optical drive bay. Instead, @Xi sells optional external DVD and Blu-ray drives. The Xi PowerGo XT is not quite as closed as several other systems we've recently received, however. In addition to being able to remove the battery, users can easily loosen two screws and remove a panel to access the internal drive bays.

Our evaluation unit came equipped with an Intel Core i7-6700K, a 4GHz quad-core CPU with 8MB cache, a maximum turbo frequency of 4.2GHz, and a thermal design power (TDP) rating of 91 watts. This 14nm Skylake processor, which added $169 to the base price, also includes Intel HD Graphics 530. Several other less expensive CPUs are also available. @Xi also equipped our system with a high-end NVIDIA Quadro M5000M mobile GPU, with 1536 CUDA (compute unified device architecture) cores and 8GB of dedicated GDDR5 memory, increasing the system cost by an additional $1,999. The Quadro M4000M ($499) is also an option as well as a choice of three NVIDIA GeForce GTX graphics cards.

As previously noted, our system came with a 1920x1080 display. Although both the 15.6-in. and 17.3-in. versions of the PowerGo XT are available with 3840x2160 displays, those higher-resolution panels cannot be selected when an NVIDIA Quadro graphics board is included.

While 8GB of 2133MHz memory comes standard, the Xi PowerGo XT can accommodate up to 64GB of RAM. Our evaluation unit included 32GB, installed as four 8GB 2666MHz DDR4 modules, adding $299 to the system price.

There are also many storage options. Rather than the 500GB 5400rpm SATA drive in the base configuration, our evaluation unit came with a 256GB solid-state Samsung MS951 M.2 PCIe drive, adding $149. The PowerGo XT can actually accommodate two 2.5-in. hard drives

Mobile Workstations Compared	**Xi PowerGo XT** 17.3-inch 4.0GHz Intel Core i7-6700K quad-core CPU, NVIDIA Quadro M5000M, 32GB RAM, 256GB PCIe SSD	**Eurocom Sky DLX7** 17.3-inch 4.0GHz Intel Core i7-6700K quad-core CPU, NVIDIA Quadro M5000M, 32GB RAM, 512GB PCIe SSD	**HP ZBook Studio G3** 15.6-inch 2.8GHz Intel Xeon E3-1505M v5 quad-core CPU, NVIDIA Quadro M1000M, 32GB RAM, 512GB PCIe SSD	**Lenovo ThinkPad P70** 17.3-inch 2.8GHz Intel Xeon E3-1505M v5 quad-core CPU, NVIDIA Quadro M4000M, 16GB RAM, 500GB PCIe SSD	**Dell Precision 7710** 17.3-inch 2.9GHz Intel Xeon E3-1535M quad-core CPU, NVIDIA Quadro M5000M, 32GB RAM, 512GB SATA HD	**Eurocom Sky X9** 17.3-inch 4.3GHz Intel Core i7-6700K quad-core CPU, NVIDIA Quadro M5000M, 64GB RAM, two 256GB PCIe SSDs and two 2TB SATA HDs
Price as tested	$4,423	$5,223	$2,999	$3,623	$3,890	$6,781
Date tested	5/27/16	7/26/16	3/9/16	2/12/16	1/23/16	1/23/16
Operating System	Windows 10	Windows 10	Windows 10	Windows 7	Windows 10	Windows 10
SPECviewperf 12 (higher is better)						
catia-04	109.37	99.74	35.30	80.54	75.57	102.23
creo-01	94.91	93.00	32.36	66.69	55.78	84.55
energy-01	7.02	7.60	3.08	6.39	9.00	10.52
maya-04	79.26	64.78	29.50	54.93	43.43	75.56
medical-01	31.90	33.66	14.46	27.23	31.21	40.75
showcase-01	51.57	52.93	21.04	46.70	48.07	45.87
snx-02	165.04	90.15	28.55	112.86	63.33	87.30
sw-03	121.39	116.72	55.23	88.04	82.02	121.63
SPECapc SOLIDWORKS 2015 (higher is better)						
Graphics Composite	8.78	8.59	2.92	4.62	3.88	6.07
Shaded Graphics Sub-Composite	5.07	4.90	2.27	2.41	2.40	4.36
Shaded w/Edges Graphics Sub-Composite	6.54	6.31	3.05	3.42	3.21	5.58
Shaded using RealView Sub-Composite	6.65	6.49	2.32	3.41	2.85	5.07
Shaded w/Edges using RealView Sub-Composite	10.72	10.45	4.03	5.89	4.93	8.36
Shaded using RealView and Shadows Sub-Composite	7.40	7.26	2.13	3.87	2.94	5.17
Shaded with Edges using RealView and Shadows Graphics Sub-Composite	11.21	10.92	3.49	6.19	4.85	8.11
Shaded using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	18.10	18.11	3.19	7.97	5.70	6.81
Shaded with Edges using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	25.69	25.53	4.62	12.01	8.74	10.28
Wireframe Graphics Sub-Composite	3.91	3.86	3.16	3.02	2.99	3.76
CPU Composite	4.96	4.95	2.82	3.47	2.56	3.03
SPECwpc v2.0 (higher is better)						
Media and Entertainment	2.37	2.93	2.29	2.60	2.57	3.38
Product Development	2.28	2.77	2.22	2.32	2.73	3.16
Life Sciences	2.40	2.98	2.46	2.56	3.18	3.91
Financial Services	1.39	1.39	1.15	1.14	1.19	1.40
Energy	2.34	2.69	2.22	2.27	2.66	3.13
General Operations	1.06	1.36	1.36	1.41	1.48	1.70
Time						
Autodesk Render Test (in seconds, lower is better)	53.10	65.7	76.80	50.00	85.60	64.90
Battery Test (in hours:minutes, higher is better)	2.30	2:28	5:18	5:15	5:30	2:17

Numbers in blue indicate best recorded results. Numbers in red indicate worst recorded results.

in addition to an M.2 solid-state drive (SSD), and supports RAID 0 or 1 configurations. @Xi offers 16 different drives ranging from 250GB to 4TB.

You can also upgrade from the standard built-in gigabit Ethernet LAN and Intel dual-band wireless AC 3165 Wi-Fi/Bluetooth module to one of two higher-end M.2 network modules. An 8-cell lithium-ion battery comes standard and kept our evaluation unit running for two hours 30 minutes before shutting down. Throughout our tests, the Xi PowerGo XT ran cool and quiet, averaging just 31dB at rest (compared to 29dB ambient background noise), climbing to just 42dB under compute loads (less than the volume of a typical office conversation).

Excellent Performance

With its speedy CPU and high-end NVIDIA graphics, the Xi PowerGo XT turned in some of the best performance we have recorded to date for a mobile workstation, tying or beating the Eurocom Sky DLGX7 we recently reviewed (digitaleng.news/de/?p=32796) on most of the datasets in the SPECviewperf tests. On the SOLIDWORKS test, the Xi PowerGo XT was the clear winner, surpassing every other mobile workstation we have ever tested.

On the very demanding SPECwpc benchmark, this @Xi mobile workstation turned in some of the best scores on many of the individual tests, although it did not garner top honors in any composite category. On our AutoCAD rendering test, the 53.10 sec. average rendering time was just barely edged out by the Lenovo ThinkPad P70, which remains the mobile rendering king.

Despite its high-end components, as equipped the Xi PowerGo XT costs $4,423 (including $59 to upgrade from the base Windows 10 Home operating system to Windows 10 Professional), $800 less than the Eurocom Sky DLGX7. That price also includes @Xi's standard warranty, which covers labor for three years but only one year on system parts. This can be extended to two or three years for an additional $149 or $239, respectively.

Like similar systems, the Xi PowerGo XT is meant to be a desktop workstation replacement. Its high high-end components deliver great performance, but at the price of weight, cost and limited battery life compared to offerings from more mainstream manufacturers. As such, it is likely to appeal to a smaller set of users for who value speed more than price. For them, the Xi PowerGo XT definitely delivers. **DE**

David Cohn *is the senior content manager at 4D Technologies. He also does consulting and technical writing from his home in Bellingham, WA and has been benchmarking PCs since 1984. He's 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 dscohn.com.*

INFO ➜ @Xi Computer: @XiComputer.com

Xi PowerGo XT

- **Price:** $4,423 as tested ($1,679 base price)
- **Size:** 16.46x11.10x1.52 in. (WxDxH) notebook
- **Weight:** 8.38 lbs. as tested, plus 2.3 lb. power supply
- **CPU:** 4.0GHz Intel Core i7-6700K quad-core w/8MB cache
- **Memory:** 32GB DDR4 at 2666MHz
- **Graphics:** NVIDIA Quadro M5000M w/ 8GB memory and 1536 CUDA cores
- **LCD:** 17.3-in. diagonal (1920x1080), non-glare
- **Hard Disk:** 256GB Samsung M.2 PCIe 3.0 SSD
- **Optical:** None
- **Audio:** Line-in, microphone, headphone, S/PDIF-out, plus built-in microphone and speakers
- **Network:** Integrated Gigabit Ethernet (10/100/1000 NIC) with one RJ-45 port, 802.11a/b/g/n/ac wireless LAN, and Bluetooth 4.2
- **Modem:** None
- **Other:** Four USB 3.0 (one powered), one USB 3.1 (Type C) Thunderbolt port, two DisplayPorts, HDMI-out, 2MP webcam, 6-in-1 card reader
- **Keyboard:** Integrated 102-key backlit keyboard with numeric keypad
- **Pointing device:** Integrated 2-button touchpad and fingerprint reader

Manufacturing Goes Digital

Software and hardware for the new era of manufacturing advances additive technology.

BY JESS LULKA

PRODUCTION-LEVEL additive manufacturing (AM) is entering the industry spotlight. In September, GE announced its intent to acquire industrial AM companies Arcam AB and SLM Solutions Group AG for $1.4 billion. Siemens also stepped up its stake in the technology by becoming a major stakeholder in Materials Solutions Ltd., a provider of AM processing and production. More companies are beginning to invest in AM because they see them as integral to their digital manufacturing plans.

"Additive manufacturing is a key part of GE's evolution into a digital industrial company," said Jeff Immelt, chairman and CEO of GE, via a press release. "We are creating a more productive world with our innovative world-class machines, materials and software. We are poised to not only benefit from this movement as a customer, but spearhead it as a leading supplier."

Digital manufacturing integrates the use of design, simulation and data analytics software to simultaneously produce products and develop best practices for manufacturing. Its goals include increased collaboration between design and production as well as collecting usable information for both departments.

"As you're producing parts [with digital manufacturing], you're learning more and more about how that part is made … so by the time that individual product rolls off the production line, you have a tremendous amount of information of how that part was designed and how that part was produced," says Dean Bartles, chief manufacturing officer and executive director at the Digital Manufacturing & Design Innovation Institute (DMDII).

GE says it expects to grow its new additive business to $1 billion by 2020 and also expects $3-5 billion of product cost-out across the company over the next 10 years. Other examples of advancing the industrial integration of AM include Siemens PLM Software partnering with Stratasys and DMG MORI; 3D Systems linking up with PTC; and the DMDII expanding its grants and research projects.

According to DMDII, 81% of U.S. manufacturers recognized digital manufacturing as an element of competitiveness, but only 14% believed that they were adequately equipped with related technology and expertise. The factory of the future will include three main things: intelligent automation, robotics and

The Robotic Composite 3D Demonstrator from Stratasys uses a robotic arm with an extruder for greater motion control. *Image courtesy of Stratasys.*

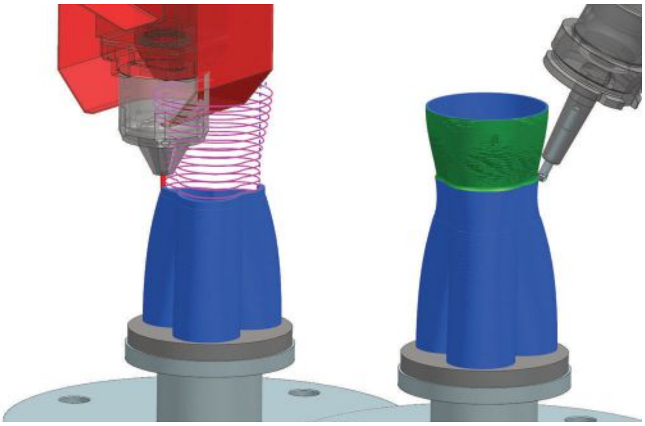
additive manufacturing, according to Aaron Frankel, marketing director for Manufacturing Engineering Software at Siemens PLM Software. "A digital environment unites the digital and the physical—and it does it in such a way to create a digital twin," he notes. "We're at the very beginning of seeing additive being used in industrial processes."

Bringing Systems Up to Speed

One way AM vendors are advancing their products is by integrating robotics to automate the process. Over the past several months, 3D Systems and Stratasys have announced new technologies to address manufacturers' needs: Figure 4 from 3D Systems and an Infinite-Build 3D Demonstrator and Robotic Composite 3D Demonstrator from Stratasys.

All three of these systems leverage robot technology for more flexible, faster and larger builds. 3D System's Figure 4 technology builds on an original patent from co-founder Chuck Hull. The vat-based stereolithography system uses multi-mode polymerization and robotics to complete production, material recovery and curing. To produce a part, the build plate is pulled up from the material and cured through a chemical process.

Stratasys' systems rely on its FDM (Fused Deposition Modeling) process. The Infinite-Build 3D Demonstrator creates parts on a vertical plane, for increased scale and greater part size. A robotic arm is used to automated material replacement during the build. The Robotic Composite 3D Demonstrator brings greater design capabilities by attaching an extruder to an 8-axis robotic arm motion system driven by Siemens PLM Software's NX, eliminating the need for support structures.



Siemens' NX Hybrid Additive Manufacturing provides laser and NC programming with simulation for the DMG MORI Lasertec machine tool series where metal deposition is incorporated with machining on a single machine. ***Image courtesy of Siemens PLM Software.***

In addition to the announcements from 3D Systems and Stratasys, this year's International Manufacturing Technology Show (IMTS) brought many other systems into the spotlight. ExOne, Renishaw and EOS North America were among the companies sporting new production-level and metal-based systems.

Last year, ExOne announced its Exerial additive manufacturing system, which is designed for simultaneous, large-scale printing. It is equipped with two job boxes for greater print capacity and sports a total build platform of 3,168 liters using binder jetting technology.

Renishaw showcased its RenAM 500M production system, which uses metal alloys for end-use level products. Functions such as powder sieving and recirculation are all automated, and it is designed to reduce handling of materials.

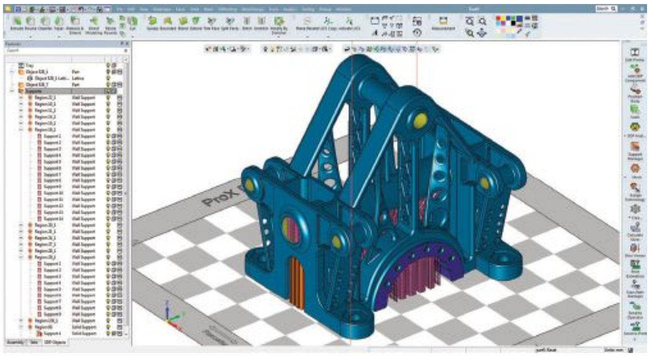
EOS introduced its FORMIGA P 110 system that directly uses CAD data to produce polymer parts in a build space of 7.8x9.8x13 in. The company says it has a high degree of automation for material handling and integration, allowing for "minimal downtimes and increased productivity."

One key common feature in these systems is an increased degree of automation. For example, 3D System's Figure 4 would be slowed down by manual intervention. "Because of the velocity at which it can produce recurring geometry, and with the scale we can get to using multiple modules, automation is just a natural part of it," says Scott Turner, senior researcher at 3D Systems. "Having labor trying to handle hundreds of parts an hour can be difficult."

Software and Time Savings

AM hardware is only part of the digital manufacturing solution. Software integration and design-to-production collaboration is only possible via a digital thread that connects the product lifecycle. With the two-way connection between manufacturing and engineering design, any changes throughout the design process or in the original CAD files can be implemented in real-time.

When it comes to creating support structures, converting files and selecting post-processing settings for AM, "the software tools will enable [engineers] to optimize the printing process," says Sridharan Hariharan, director of Applications Engineering & Training, Software Business Unit at 3D Systems.



3DXpert provides an all-in-one toolset for metal 3D printing and production. ***Image courtesy of 3D Systems.***

3D Systems introduced 3DXpert last month to provide an end-to-end process for design, pre-printing preparations (support generation, topology optimization) and post-printing processes (subtractive manufacturing or finishing, for example). It uses an original CAD model as the basis of the AM-made part and provides complete control of the printing process, including zoning

"Especially for [engineers] using additive manufacturing and having post-printing operations, [3DXpert] will enable them to be more efficient, more productive," Hariharan says. This ability to access various manufacturing methods within one software suite will help integration of metal additive manufacturing into traditional manufacturing environments, he adds.

Additionally, having a digital copy of the part for production allows for easier reproducibility, and the ability to capture the most optimized design. This almost makes it a self-improving process, Frankel says. With a software-based backbone, manufacturing environments can predict performance and accumulate knowledge to capture the best way to do things. It's also easier to transmit new workflow changes because the environment is completely connected to a software infrastructure.

This combination of hardware, software and industry partnerships is just helping set the stage for next-gen manufacturing. "Technology developers and adopters need to continue to stay open and work together to figure out what works best," Frankel says. **DE**

Jess Lulka *is associate editor of* DE. *Send e-mail about this article to de-editors@digitaleng.news.*

INFO ➜ **3D Systems:** 3DSystems.com

➜ **Arcam AB:** Arcam.com

➜ **Digital Manufacturing & Design Innovation Institute:** DMDII.UILabs.org

➜ **EOS:** EOS.info

➜ **ExOne:** ExOne.com

➜ **GE:** GE.com/stories/brilliantfactory

➜ **Siemens PLM Software:** Siemens.com/PLM

➜ **SLM Solutions:** SLM-Solutions.us

➜ **Stratasys:** Stratasys.com

➜ **Renishaw:** Renishaw.com

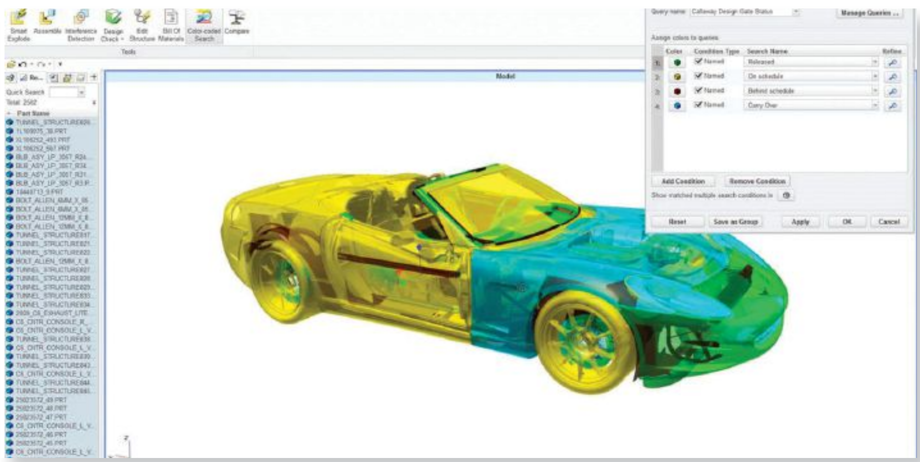
For more information on this topic, visit digitaleng.news

Changing Times for Change Management

Mobile apps, augmented reality and compliance check mechanisms are essential tools in the era of smart products.

BY KENNETH WONG

A MAJOR BATTLE IN ENGINEERING change management has already been fought and won. The struggle was between the style that favored data control and the approach that promoted collaborative product development. The former change management strategy, accomplished with a mix of file locking and access limits, is now supplanted by model-based design, only achievable by multidisciplinary collaboration involving a wider circle of stakeholders. The new struggle is to find efficient ways to offer transparency, facilitate collaboration (both asynchronous and real-time) and comply with myriad regulations (both regional and international).



Using a color-coded display, PTC Creo View makes it clear which items are on schedule, beyond schedule and released. ***Image courtesy of PTC.***

Because smart products are becoming the norm, change management tools, such as PLM (product lifecycle management) programs, may need to keep up. Many vendors are incorporating augmented reality (AR), compliance check mechanisms and mobile applications to make change management easier.

A Low Threshold for Clunky UX

Now considered one of the greatest sins of user experience (UX) design, complexity was once a standard feature of enterprise software. Some vendors justified it as a necessity in tools that must juggle complex data transactions. Accepting it as unavoidable, and many users put up with it. But the mobile app culture changed that.

"The basic tenet in mobile apps is, it must require no training," says Steve Chalgren, executive VP of Product Management and chief strategy officer at Arena Solutions. "But enterprise software didn't have that rule governing it. So vendors added complexity without worrying so much about training. In fact, training was a source of revenue for many."

The unspoken business rule today is if you're not on mobile, you're at risk of becoming irrelevant. And going mobile means adopting the golden rule of apps commerce: simplicity. The same applies to change management tools in PLM.

"The big change coming is not so much in the process but in UX," says Chalgren. "We need to make it easy for people to understand what's been changed [in the product design] so they can digest and approve it, in an app that needs no training."

Most PLM vendors today offer mobile apps that perform a subset of the operations possible with desktop clients. Siemens PLM Software's Teamcenter Mobility and PTC's Windchill Mobile fall into this category. The vendors who don't yet offer mobile apps generally facilitate mobile devices by supporting mobile-friend browsers. Dassault Systèmes currently doesn't offer a mobile apps for its 3DEXPERIENCE platform and ENOVIA products, but they can be accessed and run from mobile web browsers. Beginning in the mid-2000s, Arena Solutions has supported mobile access to Arena BOMControl through mobile browsers.

PLM vendors with integrated CAD packages also tend to offer mobile CAD file viewers to allow those outside engineering to view, discuss, annotate and comment on 3D files with pending revisions and changes. Siemens PLM Software's Solid Edge Mobile Viewer and JT2Go, PTC's Creo View Mobile, and Dassault Systèmes' eDrawings Mobile are examples of such apps.

Design Review in AR

With the advent of affordable augmented reality (AR) and virtual reality (VR) hardware, engineering teams now have another way to preview and study proposed design changes. "Design review is part of the change process," says Francois Lamy, VP of PLM Solutions and Strategy at PTC. "Today, design review preparation is very time-consuming. PLM can facilitate the preparation tasks by collecting all the relevant information, including 3D representation and then leveraging AR to share the information and collect feedback to be integrated in the change process. This digital process will also facilitate collaboration."

Through its AR-focused Vuforia division, PTC offers VuMark, part of Vuforia 6. "VuMark is a customizable visual code that can be affixed to any product or machine—either manually using a decal, or automatically printed during the manufacturing process," PTC writes. "It is intended to visually indicate to a user that an AR experience is available, such as step-by-step instructions for assembly, use, cleaning, repair, inspection, etc."

Lamy adds: "You can take the VuMark [a printed computer-generated icon that the AR app can interpret as a 3D model], view it from an iPhone or iPad to look at the changes and validate it. From an intellectual property (IP) perspective, it's pretty interesting. You're not sending out a CAD file; you're sending a VuMark and sharing the AR experience with the participants in the design review process."

Sending a CAD file or even a lightweight 3D model carries the risk of someone reverse engineering the product from the digital data. On the other hand, the VuMark, which operates like a QR code, doesn't contain any 3D geometry that can be extracted. Therefore, it prevents the possibility of IP theft.

"VR can enable the simulation of the final experience of the product for various stakeholders—the user/operator, the maintenance people, and the manufacturing/assembly workers, for instance," says Naim Dalal, senior ENOVIA UX manager at Dassault Systèmes.

Dassault Systèmes' 3DEXPERIENCE platform offers technologies to display 3D data in immersive CAVE environments, or in specialized hardware like zSpace, a Dassault Systèmes partner. eDrawings Mobile from the company's SOLIDWORKS division includes AR viewing tools.

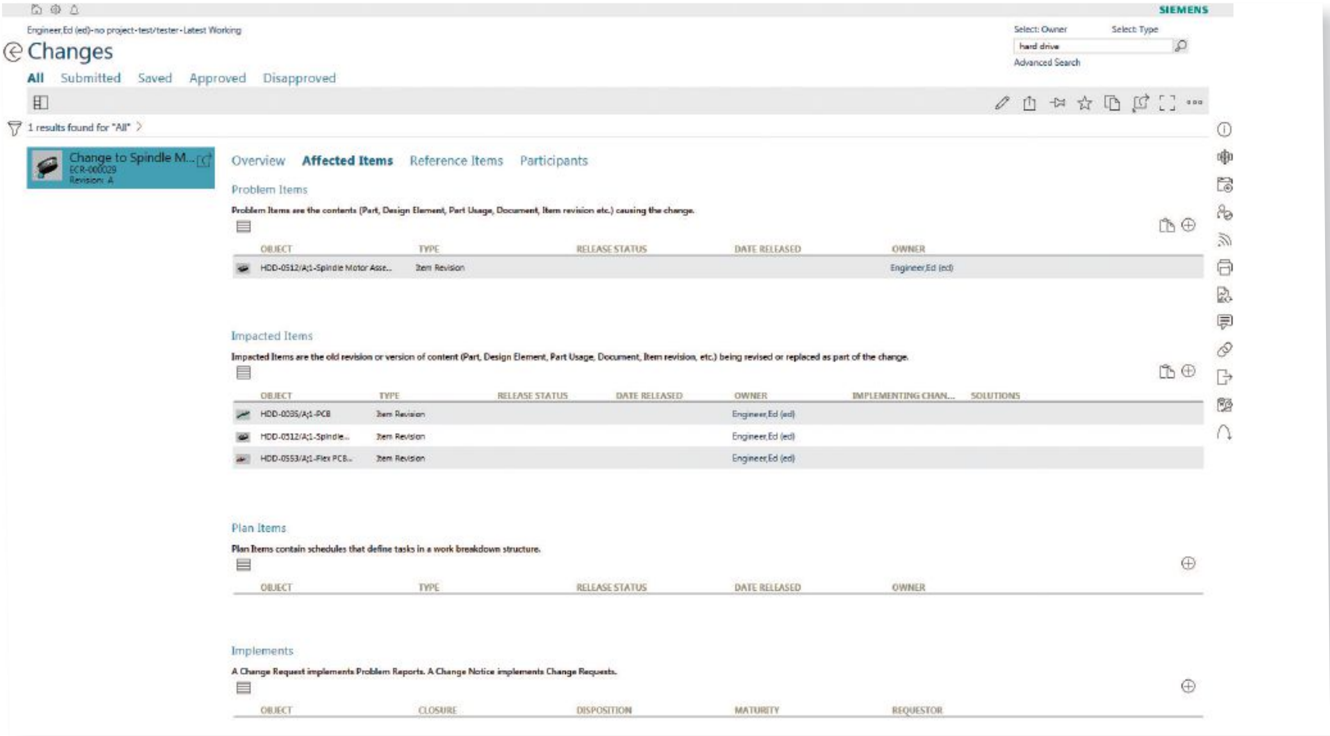
AR-powered design review could also help tackle change impact from a knowledge standpoint. "If there are manufacturing deviations, for instance, those in the field may have to use a special technique to install a part," says Bill Lewis, Siemens PLM Software's director of Marketing. "That knowledge can be identified and captured in AR."

Siemens PLM Software offers JT2Go, an in-house developed app to view 3D models in the widely accepted JT format on multiple hardware platforms, including the Microsoft HoloLens. The company allows third parties to harness its APIs (application programming interfaces). Light Guide Systems from OPS Solutions, a gesture-operated app recently demonstrated at Siemens PLM Software's analyst event, is one of the resulting products. The AR-powered design review app offer an easy way to capture as-built conditions, which could be used to kick off the Corrective Action sequence.

AR-incorporated mobile apps could also be much more inclusive than shared CAD models. Whereas CAD software is largely confined to engineering and design, product data delivered in lightweight formats to mobile devices has a wider, more accessible audience. AR's ability to merge pixel-constructed product models with real-world environments captured in the mobile device's camera gives those outside engineering an easier way to understand the impact of design changes.

Cost and Compliance

One primary reason to closely monitor changes is to prevent potential cost overruns. "Early stage cost estimates tend to be pretty accurate, because they're usually based on previous pro-



This view in Siemens PLM Software's ActiveWorkspace shows items affected by a change. ***Image courtesy of Siemens PLM Software.***

grams," points out Lewis. "Then, because of engineering and design changes, the project may need more materials, or less; it may need a different manufacturing process. But engineers aren't able to reflect on these consequences while they're making the changes."

Siemens PLM Software's Teamcenter offers a Product Cost Management module. According to the product home page, the module can "calculate complex assemblies and versions accurately and quickly; reproduce the entire price structure of your products and variants based on the bills of materials (BOMs) and bills of process (BOPs); determine and itemize direct costs and overheads, manufacturing steps and processes and materials and process parameters."

Furthermore, it includes "an extensive and cost-relevant database ... to simulate different scenarios, including production sites, machines, and pre-configured reference processes for numerous manufacturing technologies and cost rates."

You can rough out the manufacturing process with the module, says Lewis, "using the time and cost it takes on a particular machine; you add the labor rate based on a region, whether it's to be made in China or Germany, for example; you add material cost, energy cost and so on. So when you make a change, you can enter the change into the cost model, and it will give you a new cost."

The increase in environmental regulation adds a new dimension to change management. "Every country is adding new environmental regulations—more and more," says Lamy. "And every company is dealing with global product development. So project managers need to have good visibility into the compliance and sustainability content of their products."

PTC addresses this with its Materials Compliance Solution, part of the company's Windchill software. The product tackles, among other things, the regulations governing conflict minerals. PTC writes that it lets you "[perform] part, product, and supplier level analysis to ensure compliance with numerous evolving regulations and customer requirements; ... collect supplier data using automated data requests, industry standards, custom templates; protect revenue streams by making compliance risk analysis part of standard development processes; [and] demonstrate product and supply chain compliance ... with detailed, data-rich audit trails and reporting capabilities."

"Compliance goes further than the CAD model; it affects the supply chain," Lamy says. "If I'm going to design a product, I need to know which of the suppliers I can use to be compliant. I need to shop for suppliers based on my regulatory needs."

Dassault's Dalal notes that ENOVIA users can conduct a cross-functional change assessment process directly from the change order. "This capability provides the global team with a visibility on all related data that might be impacted by this change, such as: where the [changed item] is currently being

Users can create a change order in the bill of materials (BOM) in Siemens PLM Software's Active Workspace 3.2. *Image courtesy of Siemens PLM Software.*

used/consumed, which specifications are related to it, the child parts (as noted in the engineering bill of materials, or EBOM), and so on," he says. "ENOVIA also provides other impacted organizations within the company with a way to submit an impact analysis report that can include financial risks, impact on schedule/ quality, etc."

Pricing and Progress

Aside from the technology, evolving PLM pricing practices may also widen the circle of change management. The shift from perpetual licensing and on-premise systems to subscription-based, cloud-hosted SaaS (Software-as-a-Service) style PLM allows a greater pool of users to participate in the discussions about change impact. Some established vendors in the PLM space, like Autodesk and PTC, offer modular PLM products on subscription. Aras offers its Innovator PLM solution for free, and then charges for pay-as-you-go training and consulting or an annual subscription that includes upgrades. Arena Solutions entered the market with a cloud-based multi-tenant BOM management product, BOM.com.

Change management tools in PLM have significantly improved, but many critical processes, such as impact analysis and cost control, largely remain manual; they rely on the expertise, diligence and timely input of the human reviewers to kickoff and complete the workflow. The next step in change management may be the development of rule-based, algorithm-driven tools, capable of not only spotting but also predicting cost overruns and manufacturing problems invisible to the naked eye.

"Ten years ago, impact analysis was mostly based on the parts used in an assembly. Today, it's much broader," Siemens PLM Software's Lewis observes. "If you change a part, the ecosystem it lives in, has to be re-evaluated. The part is used in this assembly, but is manufactured in that plant, using this process, with this material, selling into these regions, governed by these regulations. All this knowledge is built into PLM, so the system is getting smarter. It has gotten the point where it can start suggesting things you should look at as alternatives." **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.*

INFO → **Aras:** Aras.com

→ **Arena Solutions:** ArenaSolutions.com

→ **Autodesk:** Autodesk.com

→ **Dassault Systèmes:** 3DS.com

→ **PTC:** PTC.com

→ **Siemens PLM Software:** Siemens.com/PLM

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EDITOR'S PICKS

*Each week, **Tony Lockwood** combs through dozens of new products to bring you the ones he thinks will help you do your job better, smarter and faster. Here are Lockwood's most recent musings about the products that have really grabbed his attention.*

NVIDIA Announces Quadro GPUs

P6000 and P5000 are based on the Pascal architecture.

The Quadro P6000 and the Quadro P5000 are built on the Pascal architecture, which is engineered for intensive visual computing applications like CAD, CAM and VR.

The P6000 has some impressive specs. For example, it has 3840 parallel-processing cores, 12 TFLOPs of FP 32 performance and 24GB of GDDR5X graphics memory.

The P5000 GPU offers 2560 parallel-processing cores and 16GB of GDDR5X memory.

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ANSYS Releases Version 17.2

Highlights include expanded multiphysics coupling and antenna design tools.

ANSYS 17.2 has lots of new functionality and enhanced multiphysics coupling, especially for engineers designing antennas, electric machines, embedded systems and powertrains.

For aerospace, automotive, energy and rail mission- and safety-critical applications, ANSYS 17.2 provides a complete workflow from software requirements through software design and code generation to software testing and verification. Links to requirements management tools have been improved.

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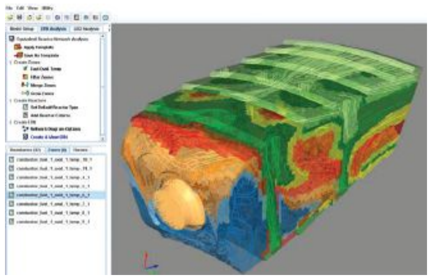

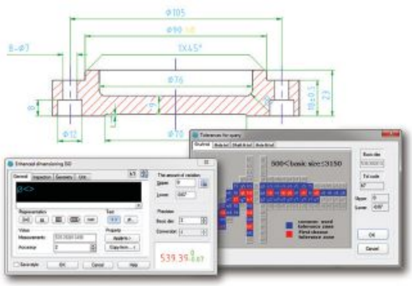

ZWCAD Mechanical 2017 Now Available

Features for shaft and gear generation have been added.

ZWCAD Mechanical is a version of ZWSOFT's ZWCAD professional-level design and drafting software that has been equipped with an extra mechanical module providing the tools for 2D drawing favored by manufacturing.

It has things like a shaft and gear generator that lets users create what they need by entering the geometric parameters. It has a variety of tools for tolerance dimension. Its smart dimensioning tools automatically force overlapping dimensioning to space themselves appropriately.

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EOS Debuts M 400-4 DMLS System

It is designed for industrial applications that require speed and volume.

The new EOS M 400-4 DMLS is designed for industrial applications where speed and volume are imperatives. It's modular, so it should fit in available shop space without fuss.

It sports a 15.8×15.8×15.8 in. (400x400x400 mm) build volume, 100 cubic centimeters per hour high build rate, scanning speed of up to 23 ft./sec (7.0 m/s) and a focus diameter of about 0.004 in. (100 µm). It also uses a lot of automation and has a task-based touchscreen interface.

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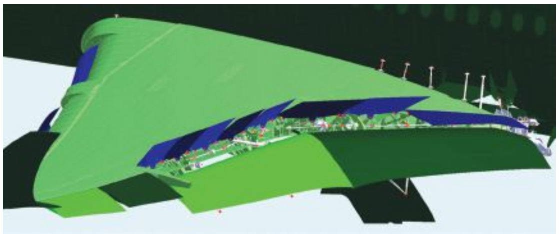
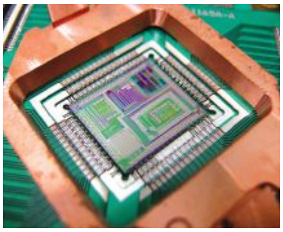


Visualizing Data: Illustrating Complex Quantum Matter Principles

BY DR. ROBERT GREEN, *POSTDOCTORAL FELLOW, QUANTUM MATTER INSTITUTE*



In the field of quantum matter research, we seek to uncover materials with properties that may find applications in new technologies. My team and I study the properties of various materials at an atomic level to find innovative ways that they can be used to compose the next generation of computer chips. Our research results in large amounts of experimental data. One of the toughest challenges is to analyze and present the data in a meaningful way, for not only our understanding of their underlying complex, quantum principles, but also for wider audiences, including fellow researchers in the field.

Examining the Challenge

One of our key research projects aims to uncover properties in materials that might be used to make smaller, more energy efficient computer chips—five to 10 years from now. In accordance with Moore's Law, the number of transistors and overall processing power within a chip has doubled every two years for over four decades. However, conventional practices of making chips are straining the laws of physics to incorporate more transistors within a shrinking area. To meet the computing needs of today and the future, we as scientists must look for new ways to continue the progression toward more energy-efficient chips that provide even greater processing power.

In our project, my team and I examined how certain materials conduct electricity and emit or absorb light, which would be conducive to smaller chip manufacturing, because electronics that incorporate light, or "optoelectronics," such as LEDs in laptops and tablets, will continue to be prevalent in the coming years. But as stated above, the experiments carried out during this project produced a large amount of raw data. Rather than attempt the impossible task of interpreting this raw data from X-ray and optical measurements directly, we needed to process the data in some way for us to extract the pertinent quantum matter information.

Advanced data analysis and graphing software helps to visualize experimental data to better understand their underlying abstract principles. Whether it is scaling the data, taking the derivative, or fitting various functions to the data, these solutions make it easy to find the most intuitive way to present and analyze the results. In our research, we use Origin by OriginLab, a comprehensive software solution for scientists and engineers at every technical level to professionally graph gathered data.

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Adams Simulation Saves Millions by Replacing Physical Testing in Aircraft Certification

Airframes are designed to deflect in response to aerodynamic and gravitational loads during flight. These deflections in turn load the mechanisms riding on the airframe that move the primary flight control surfaces to maneuver the aircraft. The airframe manufacturer must ensure that deflections of these mechanisms do not affect their operation.

For example, the Airbus A400M elevator is connected to the horizontal tail plane (HTP) with eight hinges that form a straight line when the wing is undeformed. Seven of these hinges can float in the hinge line direction. When the HTP structure is loaded, it deforms, deforming the hinge line.

Challenge

The European Aviation Safety Agency (EASA) regulation CS-25 section 683(b) requires that airframe manufacturers certify that the primary flight control surfaces used to maneuver the aircraft remain free from jamming, excessive friction, disconnection and any form of damage due to deflections of the aircraft structure. In the past, Airbus validated this requirement by building test rigs for each new aircraft. The test rigs cost millions of dollars and took months to build.

Airbus management decided to try to change the means of compliance with this regulation from physical testing to simulation. Adams multibody simulation (MBS) software was selected because of its ability to model complex mechanisms and to incorporate finite element models that are used to predict deformations of the airframe.

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AD INDEX

| **COMMENTARY** |

by Eric Miller

Documenting 3D-Printed Production Parts

THE BEAUTY OF ADDITIVE MANUFACTURING (AM) is the ability to go directly from a CAD model to a physical part. This is great for prototyping, especially when compared with traditional model making. When looking at the production of end-use parts, it is tempting to assume that this single step can be used as well. The reality is that production parts made under any proper design and manufacturing process require information beyond the CAD model.

The documentation effort for AM is less than most traditional manufacturing processes, but drawings and specifications are still necessary. Manufacturing needs to know what processes to use, acceptable tolerances, post processing and how to mark and store the part. The purpose of part documentation, usually in the form of a drawing, is to tell manufacturing and quality what the correct part is. The CAD geometry usually only contains the geometry so non-graphical attributes need to be placed on the drawing, in notes or in specifications.

> Production parts made under any proper design process require information beyond the CAD model.

A Standard Approach

The easiest way to efficiently make this type of documentation is to use standards. Engineering should develop drawing standards for parts made using additive manufacturing that define what information needs to be included on any drawings. These standards should be reviewed with manufacturing and quality control to make sure they contain all of the information that both departments need.

As with any engineering document, the key to making a good package is to assume that it will be used by someone who knows absolutely nothing about the part. Everything they need to make, post process and inspect needs to be included in the documentation package. For additive manufacturing, this should include things like which process to use, which machine type to use and possibly the required machine parameters. Support removal, surface finish and especially build orientation are also critical requirements that must be specified.

If a significant number of parts will be made using additive manufacturing, it is a good idea to invest in creating standard notes and specifications to put on drawings. As an example, instead of spelling out a given post-processing regimen on every drawing, create a standard and controlled process and simply refer to it on the drawing. This also allows manufacturing to develop process plans that fulfill the standard requirements, saving everyone time and money while delivering a consistent end-use part.

Building Documentation

An important related documentation requirement is to keep the build file used by the 3D printer. Every 3D printing method involves taking a solid model and turning it into a set of instructions that specify the layer-by-layer building process; in essence, the toolpath for the machine. This file should be stored and controlled like any set of machine instructions to ensure repeatability.

The form that this documentation takes should be determined by what is most efficient and fits in with existing company practice. The least common denominator is a detailed paper drawing with notes and dimensions, but it is also the most cumbersome. A more efficient solution would be a controlled file, mostly text with a few key figures and probably a PDF that refers to the 3D STL file, which should also be controlled. Just like notes on a drawing, it contains all of the information needed but in a concise and standard format that all potential users can easily reference. If key tolerances need to be defined and inspected, those can be on a related electronic detail drawing or included as figures in a simpler document. The key is that needed specifications are captured in a consistent and easily accessible way.

In the end, creating a document package for a 3D-printed part should be approached in the same way as any manufacture component. The distinction is the type of information required on the drawing because the process is so different, as is the post processing. But once established—along with a set of standards—3D-printed production parts will become just as simple as traditional methods. **DE**

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