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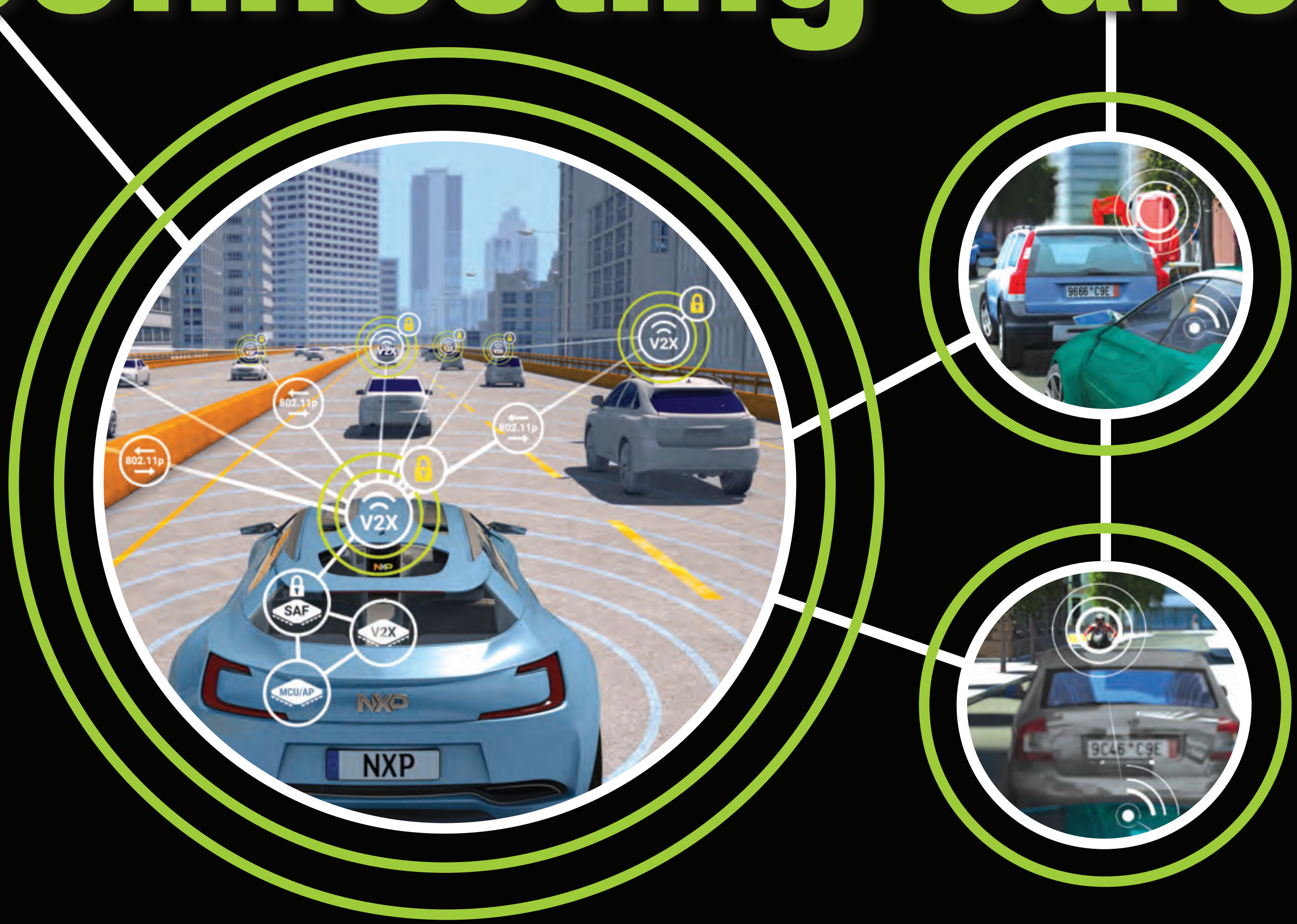
Digital Engineering

September 2018

FOCUS ON: Automotive Disruption

Connecting Cars



DEGREES OF FREEDOM

by Jamie J. Gooch

Autonomous Acceptance

IN 1909, Henry Ford made his now-famous comment: "A customer can have a car painted any color he wants as long as it's black." It appears he may have never said the even more famous adage attributed to him: "If I had asked people what they wanted, they would have said faster horses." Either way, both apply to today's approach to autonomous vehicles.

Multiple survey results (see page 6) indicate that people aren't exactly looking forward to autonomous vehicles. In fact, most people don't want to own them, ride in them or share the road with them. The collective response from Waymo, Uber, Tesla and traditional automakers seems to be: "Yes they do."

The situation reminds me of a keynote I heard at last year's Integrated Electronics Solution Forum, hosted by Mentor just after it was acquired by Siemens. Bob Lutz—a former vice chairman of General Motors who also held senior leadership roles with BMW, Ford and Chrysler—took the stage in Detroit to tell the room full of automotive engineers to enjoy driving while they can because at some point the government is going to take their cars away.

"The public won't be important in the initial transition to autonomous cars," Lutz said. "Municipal fleets, delivery, and service vehicles will be first. Gradually, the insurance companies and the feds are going to notice that 99% of the accidents are caused by the 30% of remaining human-driven vehicles. Then the next step is legislation."

Lutz envisions human-driven cars being put out to pasture, like horses at dude ranches where the public will go to get an idea of how people used to get from point A to point B. "Those of you who like to drive, I would suggest that you do as much as possible of it in the next 10 or 15 years. Enjoy yourself; take a lot of pictures."

Benefits vs. Drawbacks

In many ways, I think Lutz is right. I wouldn't hazard a guess at the time frame, but the potential benefits of autonomous vehicles are too important to be ignored. If they live up to the promises, autonomous vehicles will:

- save lives (and eliminate associated medical costs),
- reduce fuel consumption (thereby reducing carbon emissions),
- lower insurance premiums,
- reduce congestion (which should improve productivity),
- improve mobility for those who cannot drive,
- reduce car theft,
- reduce costs of car ownership (eliminating it for some), and
- become data collection treasure troves for the companies that will collect, use, package and resell that data.

On the flip side, there are some valid concerns about self-driving cars that have yet to be addressed, namely that autonomous vehicles:

- can be hacked, allowing someone to take control of the vehicle and/or steal its data,
- could lead to job loss among those whose jobs revolve around our current transportation norms,
- could have to make ethical choices, such as deciding between killing or injuring one passenger to save others,
- create privacy concerns,
- require a significant investment in roadway infrastructure to work as advertised, and
- have not proven that they are reliable in all traffic, weather and unexpected road conditions.

Those are some pretty significant drawbacks, but any reasonable look at the speed with which technology innovations are occurring leads to the question of when, not if, those drawbacks will be adequately addressed.

Technology to Build the Technology

Design engineering teams have an ever-expanding toolbox of design and simulation software, testing hardware and software, prototyping and data management products, and ridiculously fast computing solutions. If the promise of autonomous automobiles is to be realized, you'll need them all and then some. New technologies—from 5G to blockchain to augmented reality and quantum computing—are being tied into the vision for autonomous vehicles, even as the connectivity concept expands to vehicle-to-vehicle communications and smart cities.

And what about the apparent lack of consumer demand for self-driving cars? As Apple (rumored to be working on its own self-driving car technology) cofounder Steve Jobs was quoted in his biography: "Some people say, 'Give the customers what they want.' But that's not my approach. Our job is to figure out what they're going to want before they do."

That's a big job, but I think you have the tools to do it. **DE**

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DE Digital Engineering

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INSIDE

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ON THE COVER: *Images courtesy of NXP Semiconductors.*

COVER STORY

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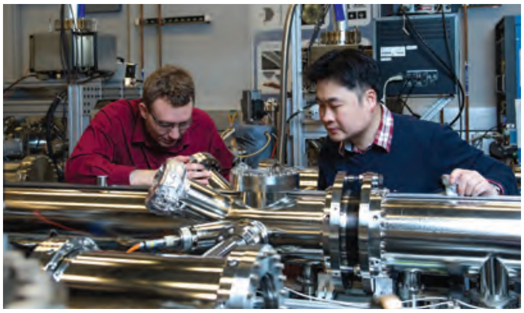

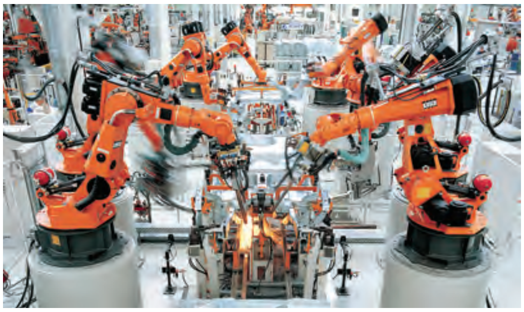

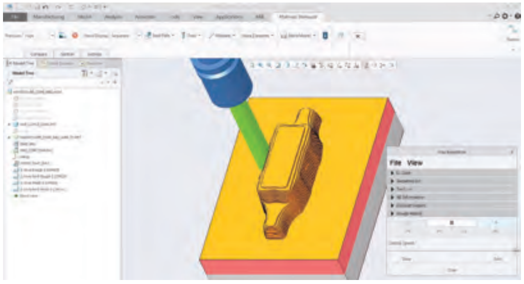

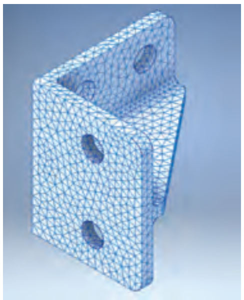

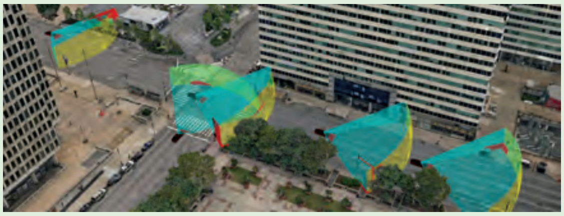

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The Self-Driving Cart Before the Horse?

57%

Would not buy a self-driving car, even if cost weren't an issue.

40%

Wouldn't trust their car to brake for them.

9%

Always trust their connected car.

— "Connected Car Drivers: A Survey on Attitudes, Use and Trust," Solace, Feb. 22, 2018

54%

Americans unlikely to use self-driving cars.

59%

Would be uncomfortable riding in self-driving cars.

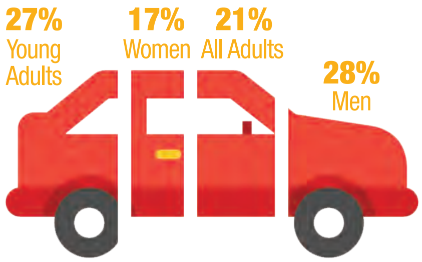
62%

Would be uncomfortable sharing the road with self-driving trucks.

— Northeastern University/Gallup survey of Americans' attitudes toward artificial intelligence (AI), Feb. 21, 2018

Polling in January found that 36% of U.S. adults said self-driving cars are less safe than human drivers. After fatal accidents involving self-driving and semi-autonomous technology from Uber and Tesla in March, that figure increased to 50% in a survey that concluded in April, 2018.

— Morning Consult survey, April 5, 2018



Only 21% of adult internet users said they are inclined to ride in a self-driving car. Men (28%) are more likely than women (17%) to say they would ride in a self-driving car. Young people aged 18 to 34 (27%) are more likely to ride in a self-driving car, compared to those 55 or over (16%).

— Brookings Institution, July 23, 2018

Why Go Autonomous?

37,461

The number of people who died in traffic accidents in 2016. That's an average of 102 per day. Motor vehicle accidents are a leading cause of premature death in the U.S. and are responsible for over **$80 billion** annually in medical care and lost productivity due to injuries.

— National Highway Traffic Safety Administration; Centers for Disease Control and Prevention

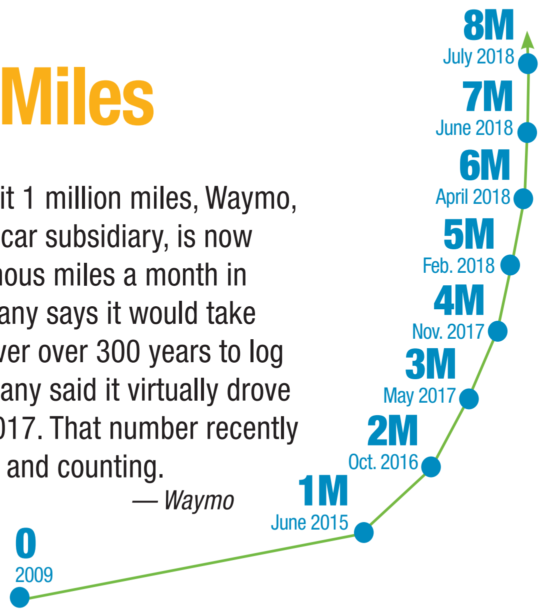
More than **90%** of U.S. car crashes are caused by human errors. If autonomous vehicles negated those errors, almost 300,000 lives could be saved each decade in the U.S. However, it is unknown if other crashes could increase via autonomous cars, such as those caused by cyber attacks.

— National Highway Traffic Safety Administration

Miles and Miles

After taking six years to hit 1 million miles, Waymo, Alphabet Inc.'s driverless car subsidiary, is now logging 3 million autonomous miles a month in different cities. The company says it would take the average American driver over 300 years to log 8 million miles. The company said it virtually drove 2.7 billion miles during 2017. That number recently surpassed **5 billion** miles and counting.

— Waymo



3,000,000,000,000

Americans drive nearly 3 trillion miles every year, according to the Bureau of Transportation Statistics.

— Via "Driving to Safety," RAND, April 12, 2016

Autonomous vehicles would have to be driven hundreds of millions of miles and sometimes hundreds of billions of miles to demonstrate their reliability in terms of fatalities and injuries.

— "Driving to Safety," RAND, April 12, 2016

Cars and Cybersecurity

67% of Americans were somewhat or very concerned about cyber threats to driverless cars, with 18% saying they were not too concerned or not at all concerned about the potential cyber vulnerabilities of self-driving vehicles.

— Morning Consult survey, Jan. 18, 2018

81% of respondents support the Department of Transportation issuing cybersecurity rules to protect against hacking of cars that are being operated by a computer. Three out of four respondents (**75%**) are not comfortable with allowing manufacturers to disconnect vehicle equipment such as the steering wheel and brake pedal without prior approval from DOT.

— Advocates for Highway and Auto Safety commissioned CARAVAN poll, December 2017.

The V2X Standards

Auto manufacturers and standards organizations weigh the options for V2X communications.

BY TOM KEVAN

MANY NEW CARS ON THE MARKET TODAY sport some form of advanced driver-assistance system (ADAS). Leveraging features like backup cameras, automatic braking, lane keeping and blind-spot detection, these systems have proven their ability to significantly enhance driving safety. To take this automotive technology to the next logical level, however, carmakers must add wireless communications. The problem is that the industry cannot agree on a single radio frequency standard to bring the vehicle-to-everything (V2X) communication network to life.

Until recently, the industry and government seemed poised to adopt dedicated short-range communications (DSRC), a technology based on 802.11p, a variant of the Wi-Fi standard. The rise of a cellular technology called C-V2X, however, has caused a pause to consider the strengths and weaknesses of each option before settling on a single wireless standard.

What Is Involved in V2X?

To appreciate the magnitude of the challenge of choosing between the two, consider what V2X is and what the selected communications standard will require.

Essentially, V2X allows vehicles to communicate with all elements of the traffic system around them. This in-

(LEFT): Vehicle-to-everything (V2X) communication promises to enable vehicles, traffic infrastructure and pedestrians, as well as cloud resources, to share information, with the goal of enhancing travel safety and economy. Currently, two technologies are competing for dominance in this arena: dedicated short-range communications (DSRC) and cellular V2X (C-V2X).

(BELOW): DSRC aims to provide a dedicated secure safety channel for secure communication of safety messages and transportation data in real time. An example of this technology can be seen in NXP Semiconductors' next-generation RoadLINK, the SAF5400. *Images courtesy of NXP Semiconductors.*

Faceoff

cludes other vehicles, pedestrians, associated cloud servers and components of the highway system. The latter category encompasses traffic cameras and lights, lane markers, streetlights and parking meters, for example. When fully implemented, V2X connectivity promises to enable the sharing of a broad spectrum of information, ranging from speed, direction of travel and braking and turning status to road conditions, weather and traffic status.

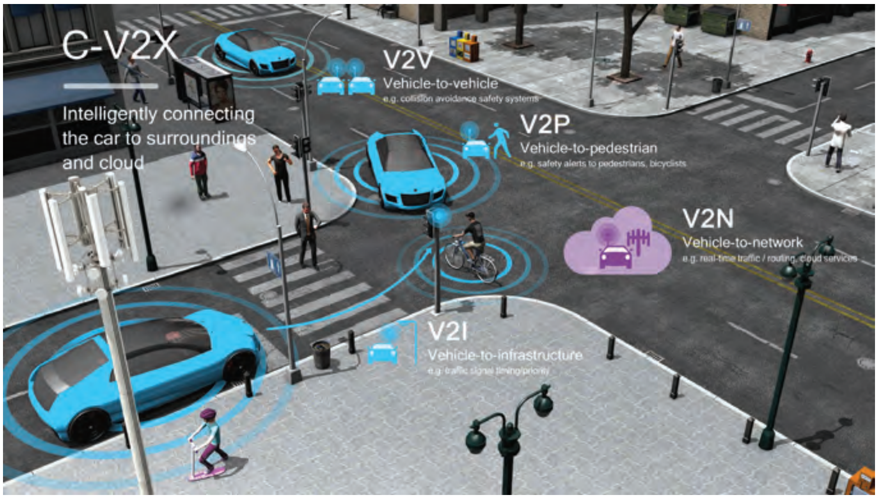
To complicate this already complex application, V2X communications involve multiple users across various scenarios. To be successful, the system must provide information to the vehicle that is relevant, accurate and cannot be acquired by a single user in any other way. Such information might include data about vehicles that are out of sight (e.g., around a corner) or information located on servers in the cloud (e.g., traffic information, ADAS HD maps or car telematics).

V2X communications interoperability is critical. Vehicles travel over large geographical areas, cutting across local and international boundaries. To deliver on the promise of V2X, these communications must operate without interruptions, even when they cross borders.

In addition to these requirements, whichever communications technology the industry selects for V2X must offer an evolutionary path to meet future demands. "Wireless vehicular technology must have simple mechanisms for evolving the technology, including the possibility of remotely reconfiguring the devices, updating device firmware and turning them off to phase out the technology when the time comes," says Ali Zaidi, strategic product manager, IoT and broadband, for Ericsson.

The comprehensive nature of the connectivity may seem daunting, but the ultimate challenge is the operating environment. "V2X technology must operate robustly in a very dynamic environment, with high relative speeds between transmitters and receivers, and support the extremely low latency of the safety-related applications in fast highways, crowded urban intersections and tunnels," says Rob Hoeben, senior director of V2X segment, automotive, NXP Semiconductors.

DSRC can work with vehicle-to-infrastructure technology to warn the driver of road construction and hazards not immediately visible to enhance driving safety. *Image courtesy of NXP Semiconductors.*



C-V2X encompasses two transmission modes: direct communications and network-based communications. Combined, these support key features of safe driving and autonomous driving systems, complementing Advanced Driver Assistance Systems sensors to provide enhanced situational awareness. *Image courtesy of Qualcomm.*

A Look at DSRC

The current technology, DSRC, has 75 MHz of allotted bandwidth, operating in one of seven 10-MHz channels in the 5.850 to 5.925 GHz segment of the spectrum. To enable traffic systemwide communications, the protocol uses variants of the Wi-Fi standards as the physical and medium access layers of its protocol stack. To optimize the technology for the cluttered, fast-moving automotive environment, the standards use orthogonal frequency-division multiplexing as a means of overcoming frequency selective fading, shadowing and high-speed hand-over difficulties.

The 802.11p standard accelerates data exchange by reducing the initial handshake and association period to a bare minimum. As a result, the protocol can transmit data almost immediately by deferring authentication, encryption and full identification to higher-level protocols. With this boost, transmitters can exchange essential data, such as speed and position information, within milliseconds of detecting each other, providing the communication speed required to enable applications like collision avoidance.

These combined factors enable DSRC systems to communicate effectively among fast-moving vehicles over distances of at least 300 meters, at data rates ranging from 3 to 27 Mbps. In addition, DSRC reduces communication latency to 2 ms.

The protocol uses the IEEE 1609.2 standard to provide for authentication and optional encryption based on digital signatures and certificates. To ensure security, the certificates do not contain information about the driver, and the system changes certificates frequently, making it difficult to track vehicles.

DSRC promises to extend vehicle situational awareness beyond what is currently provided by onboard sensor systems—which are limited by their line of sight—by leveraging vehicle-to-infrastructure connectivity. This means DSRC-enabled vehicles can enjoy 360°, non-line-of-sight awareness.

DSRC: Pros and Cons

Introduced over 10 years ago, industry engineers have attempted to tailor DSRC for safety-critical ADAS applications, as well as to position it to support emerging autonomous driving systems. The long development period has given developers of DSRC and supporting products time to work out the technology's drawbacks.

"DSRC technology has been standardized, implemented and thoroughly tested," says Hoeben. "Large investments are being made to guarantee the quality and reliability of DSRC, and several semiconductor companies have designed and tested automotive-qualified DSRC-compliant products. Many hardware and software products are available from multiple suppliers, comprising a rich ecosystem. Finally, there are several car models on the market with DSRC technology, while others are planned to be launched soon."

Others, however, see the technology's maturity as a drawback. "DSRC uses an old standard—IEEE 802.11p—which is 10 years old and is based on IEEE 802.11a, which is almost 20 years old," says Zaidi. "As such, the technology does not include most of the key advancements in wireless communications that have taken place over the past two decades. Moreover, the standard is closed and cannot be modified or enhanced in a simple way—preserving backwards compatibility and allowing forward compatibility for adding new features."

Detractors of the technology also contend that DSRC is a specific-purpose technology with no application besides vehicle-to-vehicle communication or vehicle-to-roadside-infrastructure. As such, they assert, it has limited use and requires the installation of additional communications equipment, making it more costly to deploy and operate than other alternatives.

Along the same lines, detractors see the integration of 802.11p into handsets for pedestrian and cyclist safety as a major hurdle. They claim that for several technical reasons, widespread Wi-Fi chipsets cannot support 802.11p. To do so, they say, a handset manufacturer would have to incorporate a separate, specially built 802.11p chip in addition to its Wi-Fi chip, a move that they contend would be costly and constitute a significant deployment barrier.

Additionally, critics see DSRC providing limited functionality. "DSRC/802.11p is only addressing basic safety services and has no plans to be further developed to support advanced safety features, including ADAS and automated vehicles, so-called day 2/3 services," says Maxime Flament, chief technology officer of the 5G Automotive Association.

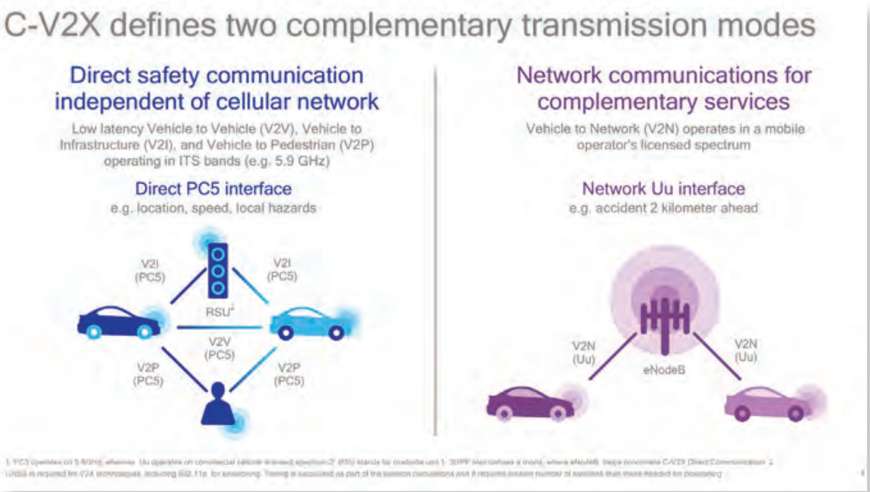
And Then There's C-V2X

The challenger to DSRC for V2X emerged from the cellular industry, tailored to complement and extend mobile network capabilities. Currently named C-V2X, the standard was initially introduced as LTE-V2X by the mobile communications standards body, the 3rd Generation Partnership Project (3GPP), in its 3GPP Release 14. The name change reflects the promise that C-V2X will provide an upgrade path from LTE to the 5G mobile standard.

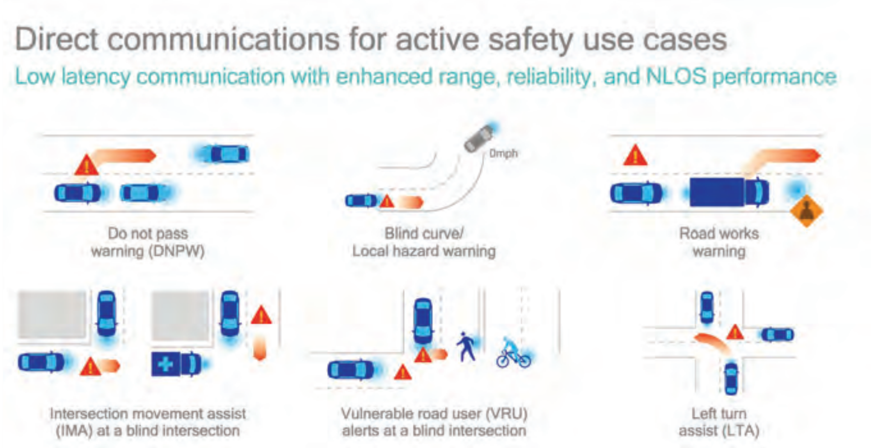
C-V2X offers two transmission modes. One provides direct communications between vehicles, highway infrastructure and other road users. In this mode, C-V2X uses the 5.9 GHz frequency band—also known as the intelligent transport system spectrum (ITS)—and operates independently of cellular networks.

Using direct communications, C-V2X can support low-latency connections over short distances. As with 802.11p, C-V2X leverages the global navigation satellite system to determine a vehicle's position and to synchronize communications between vehicles and the roadside infrastructure. This mode does not require a subscriber identity module (SIM) card because the vehicle does not connect with the cellular network. The network-autonomous operation also protects the driver's privacy because no cellular subscription is required.

C-V2X can co-exist with 802.11p in the 5.9 GHz frequency band by using different channels. The cellular–based systems require only 10 MHz of spectrum to support basic safety services. On the other hand, 70 MHz enables the systems to support advanced safety services, opening the



C-V2X technology aims to complement other vehicle sensor technologies by extending a vehicle's ability to "see" further down the road, tapping into information gleaned from other vehicles, highway infrastructure, pedestrians and network sources. *Image courtesy of Qualcomm.*



The foundation of the C-V2X is the direct transmission mode, which allows cars to communicate directly with each other, without relying on cellular networks or base stations for communication. *Image courtesy of Qualcomm.*

door for sharing large amounts of data collected by on-vehicle sensors.

The second mode operates in mobile operators spectrum band, using the conventional mobile network to enable vehicles to receive information from the cloud regarding road and traffic conditions in the area.

C-V2X can combine the capabilities of the cellular network and radio base stations called roadside units (RSUs) to improve safety services and support autonomous driving. RSUs reside at intersections or along the side of the road (e.g., on lamp poles and traffic light poles), enabling communications between vehicles and the highway infrastructure within a localized area. Designers see these RSUs leveraging high-throughput connections with other cars to build local, dynamic, high-definition maps, using camera and sensor data.

Moving forward, C-V2X release 15—which 3GPP expects to complete this month—will augment current technology by incorporating 5G New Radio features. These will include higher-throughput, wideband carrier support for sensor data from surround cameras, radar, lidar and other car sensors, enabling map sharing among vehicles or even streaming video from one car to another. Experts expect release 15 will maintain backward-compatibility with previous C-V2X releases.

Although these improvements have yet to be delivered, early tests have shown that current C-V2X data rates fall within a range comparable to DSRC's 300 m at urban driving speeds. Furthermore, test data seems to indicate that C-V2X achieves 20% to 30% better range at faster speeds.

C-V2X's Pros and Cons

Many perceived advantages of C-V2X stem from the technology's cellular base. For example, proponents assert that their systems benefit from being based on technology intended for high-speed mobile applications, pointing to test results that indicate C-V2X outperforms 802.11p in areas like alert latency and range. They also say that C-V2X can leverage all features provided by the existing cellular LTE network.

Not all parties, however, agree with this last claim. "C-V2X is a relatively new extension of cellular 4G/LTE," says Hoeben. "As a result, certain key features are not mature, and will only be partially corrected in the next release [Rel-15]."

Perhaps its greatest strength is that C-V2X casts a broad connectivity net, offering direct and network-based communications. As a result, vehicles can not only connect with other vehicles, but also with other traffic-system elements that incorporate cellular technology, such as cloud-based assets, pedestrians and cyclists with smartphones. Furthermore, advocates of C-V2X contend that 5G-based C-V2X will be a key step toward autonomous cars because it can help cars detect obstructions that aren't visible to the driver.

The cellular technology also promises cost advantages. "C-V2X is the only V2X technology positioned to be integrated into the cellular modems that carmakers plan to embed into most production vehicles—driving adoption in support of—or even in the absence of—a regulatory mandate," says Nakul Duggal, vice president of product management, automotive, for Qualcomm Technologies.

"Reduced infrastructure deployment cost is another key benefit of C-V2X, from the potential to reuse existing mobile infrastructure, and thus leveraging cellular technology integration and economies of scale rather than building independently operated roadside infrastructure," he adds.

Cost advantage claims also seem to be supported by promises of greater energy efficiency. "Unlike 802.11p devices, 3GPP Rel-14–compliant chipsets allow resource selection based on a power-efficient sensing scheme—partial sensing," says Flament. "With the partial sensing, the UE senses on the radio channel within the configured time window only, rather than the less predictable nature of carrier sense multiple access (CSMA) in 802.11p, where the clear channel assessment algorithm can require the receiver to be active frequently. Studies in 3GPP show that the partial sensing can provide similar radio performance—packet reception ratio—at the cost of much lower power consumption compared with the frequent medium sensing required in CSMA. Therefore, partial sensing would balance the radio performance and UE battery consumption for UE devices that have limited battery capacity."

Although the performance advantages claimed by C-V2X proponents have caught the attention of many in the industry, some nagging doubts remain, such as the fact that C-V2X hasn't been as extensively tested and vetted as DSRC. That said, trials are ongoing, and chips and modules are becoming available.

The Outcome?

The competition between DSRC and C-V2X continues. No decision has been made. The momentum, however, seems to be moving toward a C-V2X outcome. Cellular carriers and some semiconductor companies like Qualcomm are pushing hard for C-V2X. Now some of the carmakers previously committed to DSRC have switched sides. Furthermore, the advocacy organization 5GAA—with over 75 corporate members, leading auto manufacturers and high-tech giants like Intel—has thrown its weight behind the C-V2X agenda.

Advocates of DSRC, however, have shown no signs of giving up the fight for V2X dominance. In fact, the IEEE has begun a study group to update the 802.11p standard, with an eye toward improving its capabilities in V2X applications.

Another factor to consider is that standardizing on C-V2X would probably mean further delays. The relevant U.S. government agencies could require years of testing. This timetable would in all likelihood be unacceptable to the auto industry, given its desire to move forward with projects like ADAS and autonomous cars.

Perhaps another perspective is called for. "The best way forward to decrease road fatalities and increase road safety is a hybrid communication approach in which DSRC [5.9 GHz] and 5G cellular [3.x GHz] technologies work together," says Hoeben. **DE**

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INFO → 5G Automotive Association: 5GAA.org

→ **Ericsson:** Ericsson.com

→ **NXP Semiconductors:** NXP.com

→ **Qualcomm Technologies:** Qualcomm.com

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Autonomous Visualization

Autonomous driving visualization tools make massive testing scenarios possible.

BY RANDALL S. NEWTON

IT IS NOT HYPERBOLE to call autonomous driving development a race. Various cutting edge technologies including deep learning, general-purpose graphics processing units (GP-GPUs), artificial intelligence and computer vision are adapting to make driverless cars and trucks an everyday reality. Several vendors are pushing themselves to create the engineering tools required.

Baraja Spectrum-Scan is a lidar system for autonomous driving that replaces several spinning lasers with one stationary device. Fiber optics send and receive signals to small prisms on the exterior. *Image courtesy of Baraja.*

As with most great engineering challenges, testing is where the industry will succeed or flop. Humans average a fatal automotive crash every 100 million vehicle-miles traveled. Rand Corporation estimates it will take 11 billion miles of test driving before the industry achieves broad regulatory approval. Waymo, an Alphabet Inc. (Google) subsidiary, has logged more than 8 million miles as of July 2018. Other leading developers, including Uber and General Motors, are close behind.

"We've now test driven in 25 U.S. cities, gaining experience in different weather conditions and terrains: from the snowy streets of Michigan to the steep hills of San Francisco, to the desert conditions of greater Phoenix," Waymo announced in its blog recently. "And because the lessons we learn from one vehicle can be shared with the entire fleet, every new mile counts even more."

Simulation is the only reasonable way to log the required miles. Industry leaders and startups alike are working to adapt visualization and simulation tech for working with lidar, radar, sonar and computer vision. Others are creating virtual driving environments to simulate every imaginable driving scenario.

Two Development Stacks

Two kinds of visualization for simulation are required, says Danny Atsmon, CEO of Cognata, an Israeli startup with experts in deep learning, advanced driver assistance systems (ADAS), 3D graphics and geolocation. The first is fully rendered visualizations. "The images you get from all the sensors should look like the real thing," says Atsmon. Fully rendered visualizations of driving terrain are required to train autonomous driving and to validate results.

The second form of visualization is non-rendered. To the untrained eye it looks like polygons in motion: cars and pedestrians are rectangles; lanes are lines. It is a semantic view of the world, Atsmon says, the foundational level required to guide systems in their interpretation of the driving environment.

Two software stacks guide autonomous vehicles. The Perception stack takes the raw sensor data and creates an environmental model. "It must be able to present a car 20 meters away at 75° in the center lane," Atsmon explains. The result is data that vehicles interpret and localize. The Quality stack then makes decisions on how the vehicle interacts with the world. "Where are the objects? Where are you? What do I do?" is how Atsmon describes the work of the Quality stack. "Think of it like two parts of the brain: one part processes vision, one makes sense of the information."

Cognata's software creates digital twins for testing of both the autos and city infrastructure, the latter from existing 3D geographic data. The autonomous driving software then guides a virtual car through the virtual landscape. Sensors are recreated in the simulation, and all the road details down to traffic signs and lane lines are included. The virtual car does not drive in isolation; other cars and pedestrians, historical traffic conditions and time-of-day lighting are added to the mix. By using real-world geographic data, Cognata's dynamic traffic model can simulate driving conditions in Mumbai or the German Autobahn.

Better Lidar

One of the key sensory technologies in autonomous vehicles is lidar (laser radar), which civil engineers have been using for several years to capture 3D geographic data. Woodside Capital Partners recently predicted the lidar industry will become a $10 billion market by 2032 (up from $1.4 billion in 2017) due to rapid acceleration of its use in automotive.

Lidar for automotive is a relatively new adaptation; the market has not coalesced around a single method of use or vendor. The challenge is in how the laser moves back and forth to scan its surroundings. Velodyne LiDAR, a large lidar vendor, uses 128 lasers spinning at 64 times per second. The moving parts and complexity are fine for stationary platforms or slow-flying drones, but automotive use is proving difficult.

An Australian start-up, Baraja, is working on a new, mechanically simpler approach to lidar as an autonomous driving vision tool. Instead of multiple spinning lasers, a single laser is shot through a lens that refracts infrared light the way a prism refracts visible light. The aiming takes place by adjusting wavelengths, not moving the laser.

Baraja's co-founders came from telecoms, where a similar approach creates wavelength division multiplexing, in which light splits into many wavelengths, but travels inside one optic fiber cable. Because there is no single most-optimal point on a car for the sensor, most competing methods install lidar at several points. Baraja uses only one laser, buried deep inside the car. The light pulses travel via fiber optic cables to tiny prisms scattered around the exterior. Baraja believes its Spectrum-Scan technology will significantly lower costs of producing autonomous vehicles in two ways: initial cost of parts and lower ongoing maintenance costs by eliminating most moving parts.

Repurposing Simulation Tools

Mechanical Simulation Corporation has been a software developer since 1996, providing vehicle dynamic model simulation. It is now using its expertise to develop a new line of simulation products for autonomous driving development. The transition moves Mechanical Simulation from just the math model of vehicle behavior to its interaction with the ever-changing environment. "Simulated conditions have expanded to include running with the many built-in controllers in hundreds of thousands or even millions of simulations," says Mechanical Simulation CEO/CTO Dr. Michael Sayers.

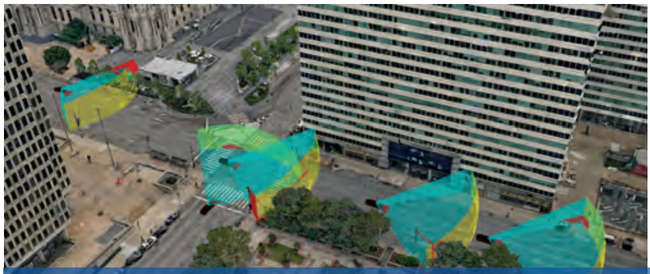
The new line for autonomous vehicle simulation includes animation resources (pedestrians, bicycles and animals), road surfaces, signage, GPS data and more. The new line supports vehicle sensors and interactive traffic, and can exchange data with MATLAB/Simulink, LabVIEW, ETAS ASCET and other engineering software.

Geospatial Data Fusion

A single autonomous vehicle can collect 4 TB of data per day. The multiple incoming data streams include camera imagery (40 MB/s), lidar points (70 MB/s) and varying amounts of time-based telemetry from GPS, gyroscopes and accelerometers. All this data must be compiled and available in real time as heterogeneous 3D geospatial datasets. Cesium has been in the 3D geospatial streaming industry for years, and is now adding autonomous vehicle development to its services. The company's past work includes software for tracking every satellite in space and creating sub-centimeter point clouds with more than 6.4 billion data points.

Cesium is only doing the autonomous vehicle visualization, leaving other parts of the autonomous vehicle development stack for others. It offers an open time-dynamic streaming format, CZML, capable of batching multiple frames of input into a single visual. The technology was originally developed for aerospace visual data fusion. Open-source Cesium 3D Tiles manages the streaming process, delivering only the parts of the 3D model needed for the current virtual view. Cesium is an open standards proponent and has developer relationships with more than 50 software vendors. **DE**

Cognata combines 3D geographic data with autonomous driving software to create virtual test drive environments. *Image courtesy of Cognata.*



Cesium supplies software for gathering and selectively streaming 3D data in real time for autonomous vehicle visualization. *Image courtesy of Cesium.*

Randall S. Newton *is managing director of Consilia Vektor (www.consiliavektor.com), a consulting service for design-based industries. He is a regular contributor to* Digital Engineering.

INFO → **Baraja:** Baraja.com

→ **Cesium:** Cesiumjs.org

→ **Cognata:** Cognata.com

→ **Mechanical Simulation:** CarSim.com

→ **Velodyne LiDAR:** Velodynelidar.com

→ **Waymo:** Waymo.com

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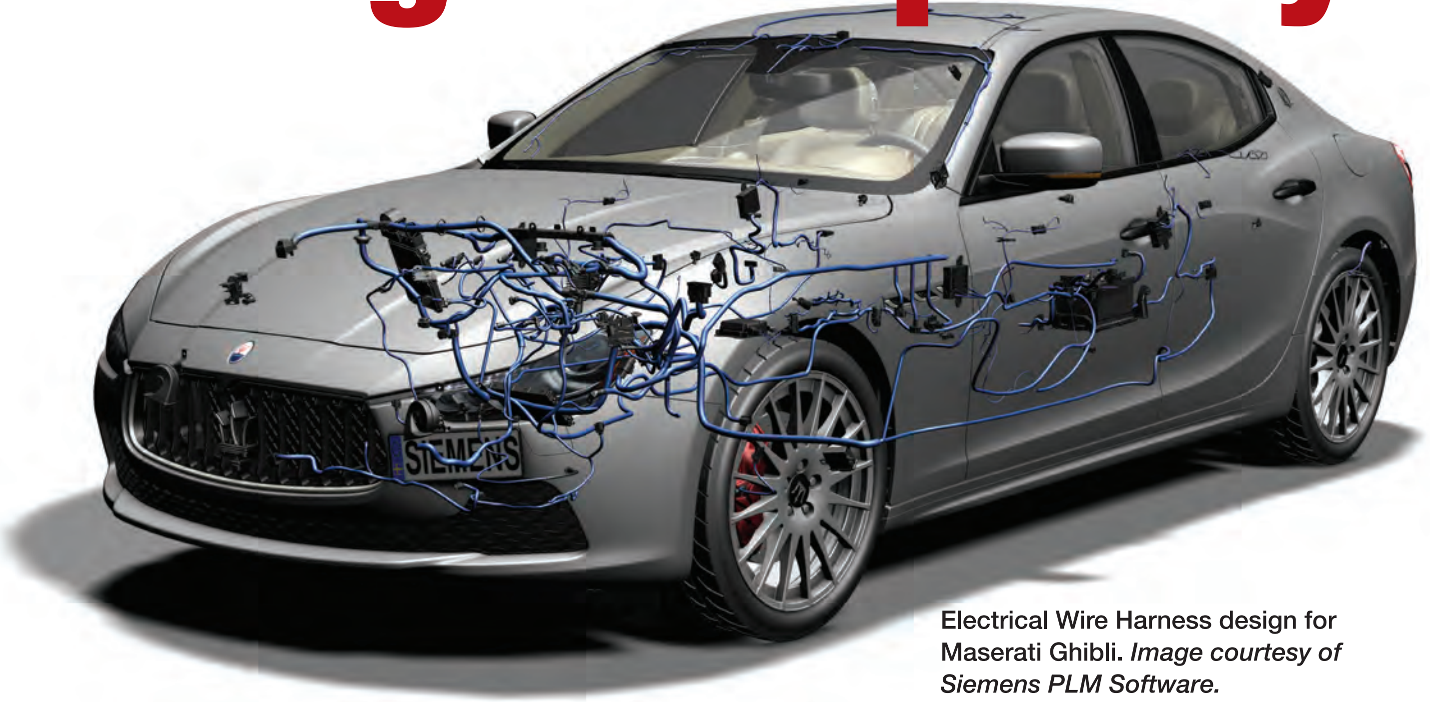
EVs and Design Complexity



Electrical Wire Harness design for Maserati Ghibli. *Image courtesy of Siemens PLM Software.*

Electric vehicles are introducing new levels of complexity to automotive design.

BY BRIAN ALBRIGHT

THE ELECTRIC VEHICLE (EV) market is expanding. Frost & Sullivan's most recent EV market outlook shows that sales are set to grow from 1.2 million units in 2017 to 2 million in 2019, major original equipment manufacturers (OEMs) such as Ford and Fiat Chrysler have big plans to expand their EV fleets over the next several years, and a number of start-ups are entering the market.

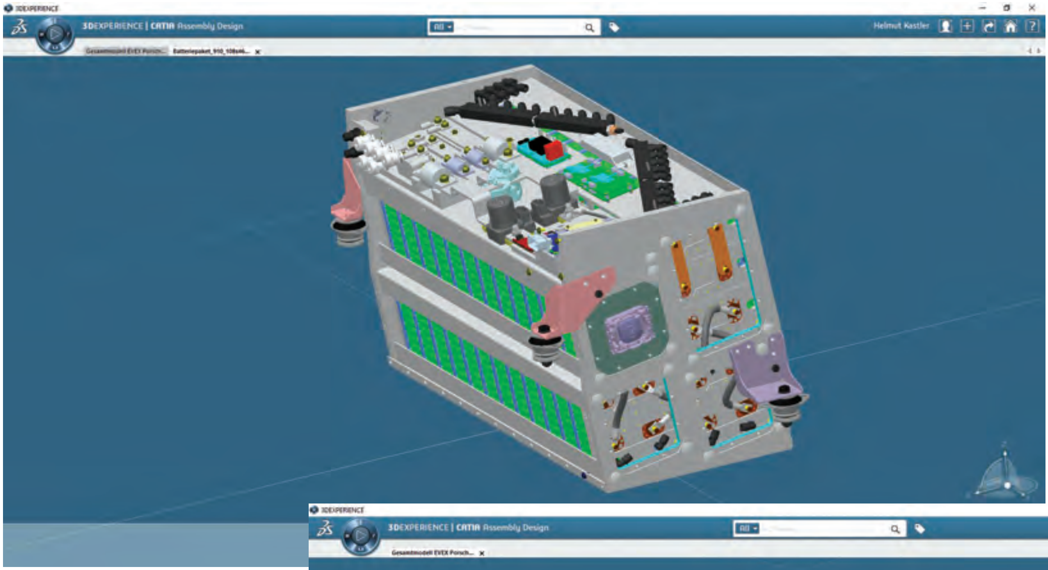
Although EVs have existed for decades, growth in the sector means that automotive engineers will face new challenges when designing for them. This will require more than just swapping out an internal combustion engine with an electric motor—there are complex engineering issues to overcome.

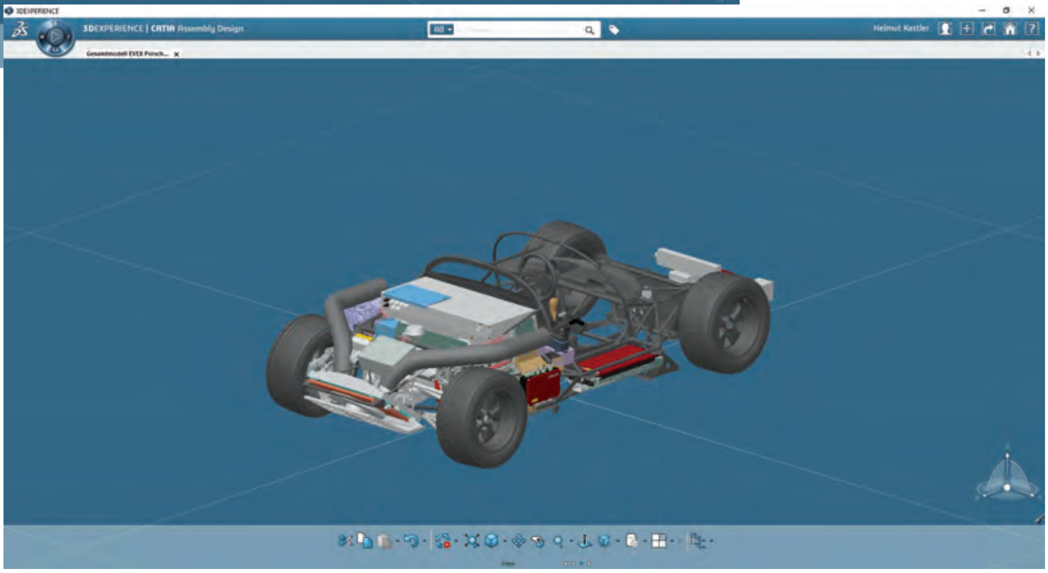
"A lot of engineers who grew up in the mechanical world now need to address the fact that a once-mechanical part is now a complex electrical mechanical device that is controlled by software," says Dave Lauzun, vice president of the automotive and transportation industries team at Siemens PLM Software.

In some regards, EVs are simpler than gas-powered vehicles because there are fewer moving parts—fewer complicated gears, bearings and other elements that govern the interaction between the powertrain and the rest of the vehicle. An ideal EV would have motors on each wheel.

However, the subsystems within an EV have introduced different types of complexity and design challenges that automotive engineers have not had to work around before.

"Each of these systems—the battery, the motor, the power electronics—comes with its own challenges that the auto industry is not familiar with," says Sandeep Sovani, director, global automotive industry, ANSYS. "Batteries, for example, have been used in other industries, but the automotive use case is pushing them beyond the existing performance envelope.





Dassault Systèmes says its 3DEXPERIENCE platform can be used to model the battery from the initial chemistry all the way to how it operates within the vehicle as a system. *Images courtesy of Dassault Systèmes.*

There are new complexities because of that."

Because the vehicle design is now arranged around a battery and one or more motors rather than an internal combustion engine, the design space is much larger and more varied than before. Engineers need to approach analysis and simulation from the system level because of the way different physics affect each other in these vehicles. "They really need to drive the whole product development effort from a model-based approach," Lauzun says.

"Engineers need to look at the complexity more at the systems level, and bring more systems together earlier in the design process," says Warren Seeley, director, powertrain, at Siemens PLM Software. "That is a mindset change."

As a result, engineers are turning to more multiphysics solutions and have a greater reliance on simulation and virtualization. It is much more expensive to build prototypes of these experimental EVs, so automakers are increasingly turning to simulation and other types of virtual testing before advancing to the prototype phase.

"Building prototypes is less feasible," says Wensi Jin, automotive industry manager at MathWorks. "Since simulation supplements design, you have a better design methodology and you can accomplish much more in the simulation space."

Mitsubishi Motors, for example, deployed a hardware-in-the-loop (HIL) simulator from dSPACE for the electrical control units in its i-MiEV vehicles (which includes five dedicated electronic control units). Other companies have turned to augmented or virtual reality to test cabin interfaces.

This type of simulation also helps with the enormous amount of software design required for EVs. "That's one of the benefits of using model-based design," Jin says. "You can do the software design as part of the simulation and run it against the vehicle model. You can generate the code that runs in the vehicle based on the actual simulation rather than going by the specifications. Customers tell us that the time savings with model-based design and code generation is as much as 30% and can even go higher than that."

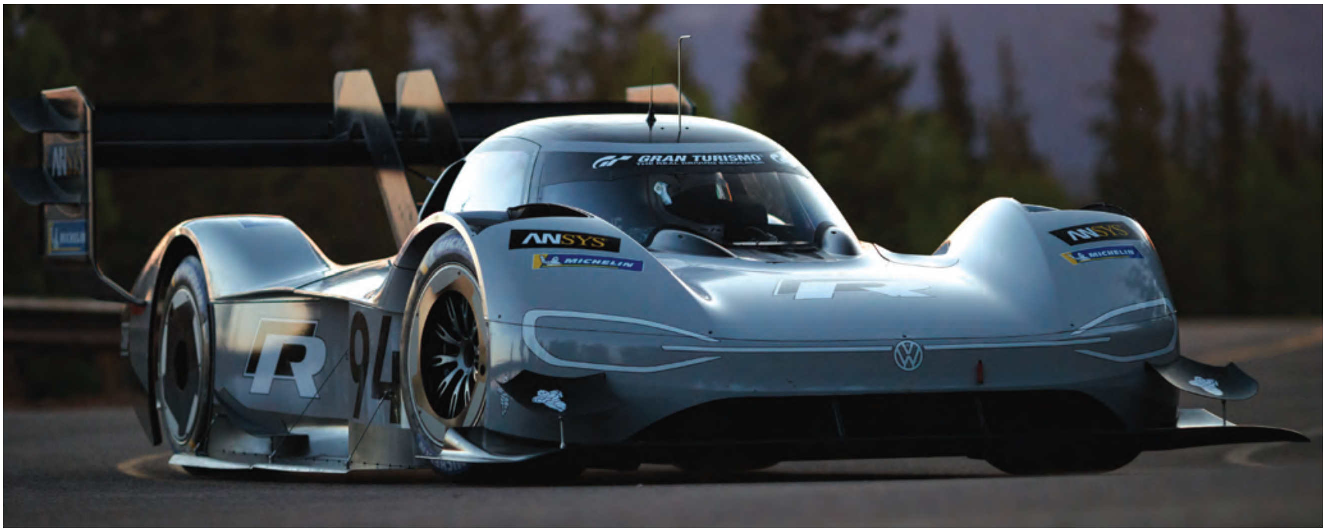
New Engineering Challenges

For EV engineers, there are a number of new and evolving challenges that electric cars present.

According to Sovani, one of the biggest is the battery design. For EVs to truly become mainstream, they need to match the performance and ease of use of gas-powered vehicles in range and time to refuel—or, in this case, recharge. That simply isn't possible with current battery technology, and engineers are wrestling with ways to bring EVs closer to that reality.

"Developing materials that can hold more charge or that can be charged and discharged without degradation is a new challenge," Sovani says. "Figuring out the right geometry of those cells is a challenge from multiple perspectives. There's a big thermal aspect to that, as batteries are extremely sensitive to temperature.

Furthermore, cooling and temperature control require a different approach than with gas-powered vehicles, and integrating these structures into a vehicle requires having accurate models of



Volkswagen's first fully electric race car, the I.D. R Pikes Peak, which was developed with ANSYS simulation solutions, shattered the time record at the Pikes Peak International Hill Climb. ***Image courtesy of ANSYS.***

the battery and other sub-systems. For batteries, that may mean the use of simulation at the microscopic level to analyze how a battery cell performs. "There are good techniques, linear time and video techniques, that can be used to capture the thermal behavior of a battery and accurately put that into a model with hardly any degradation in accuracy," Sovani says.

At Dassault Systèmes, the company has the capability to model the battery from the initial chemistry all the way to how it operates within the vehicle as a system, explains Michael LaLande, director for the North American transportation and mobility industry. "There are many conditions we can test for so we can even see how the battery will age," he says.

Noise, vibration and harshness (NVH) testing is also evolving to meet the needs of these vehicles. EVs produce less motor noise, but that lack of noise has uncovered other types of noise in the vehicle that had previously been masked.

"We're all used to the powertrain covering up a lot of sins when it comes to NVH," Lauzun says. "Everyone is struggling with the unique challenges of NVH because of the motors and conventional noises that are more prevalent now, like wind noise and other noises in the vehicle."

Software use has gone up exponentially in EVs, which can be very difficult to manage when it comes to system-level simulation and design. The electrical architecture can also present a challenge.

"The engineers are not necessarily used to working with batteries, electric drives and motors," LaLande says. "Some early adopters even purchased off-the-shelf electric motors, but they've been determined to not be durable enough to work in the automotive environment. Now [engineers] are developing their own electric drives and motors. They aren't used to working with fluid flows within motors, electromagnetism and how that may interfere with other parts of the vehicle."

With continued electrification in the vehicle, the use of multiphysics simulation has also become more important. In an electric motor, electrical, magnetics, fluid, thermal, structural and acoustic elements are closely interrelated.

"We understood where the industry was going and made an aggressive effort to fill the gaps when it came to the EV space," LaLande says. "We can now provide multiphysics across disciplines so companies don't have to use multiple sets of tools. They can solve for three or four disciplines using one tool."

While software vendors are making it easier to perform multiphysics simulations, engineering departments also have to change their processes and culture to improve integration.

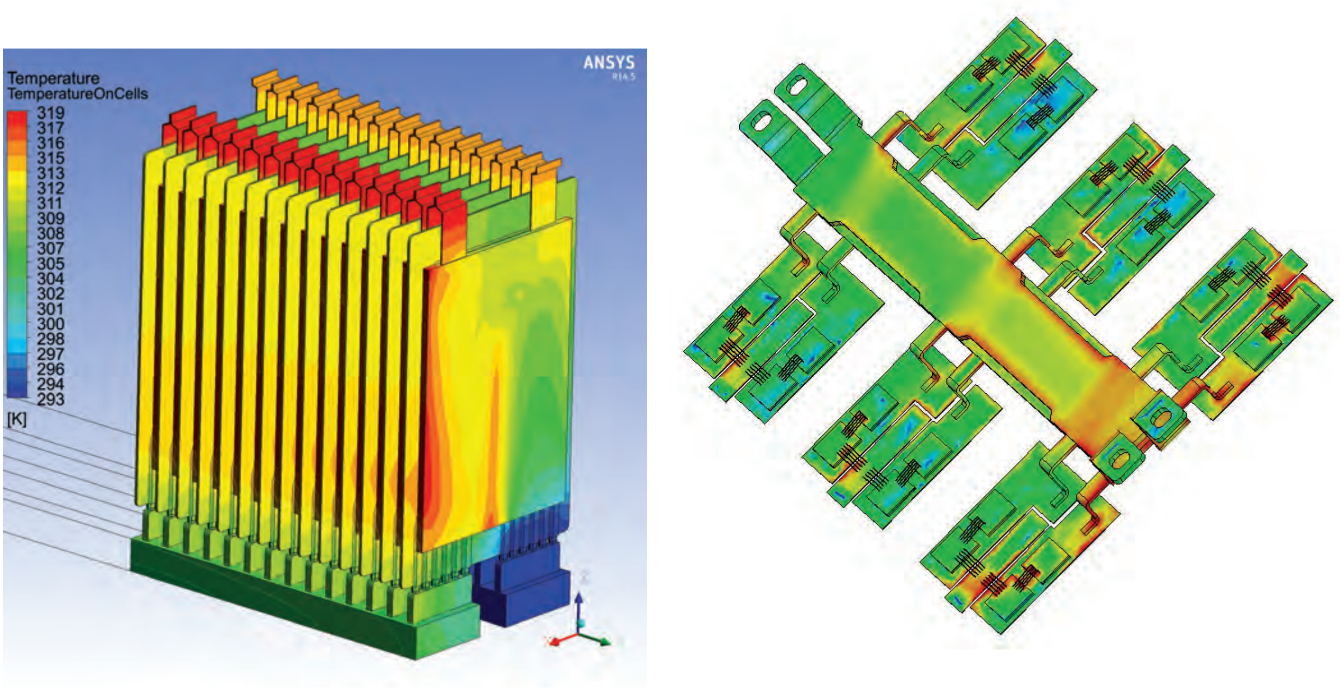
"It's no longer good enough to do a thermal analysis in isolation or a vibration analysis in isolation," Lauzun says. "You want to optimize the entire vehicle."

ANSYS is pushing for more model-based systems engineering for such multiphysics simulations, and co-simulation of hardware and embedded software.

Lucid Motors in Menlo Park, CA, worked with ANSYS on its own EV design. The company's process involved putting all of its engineers in one room to encourage collaboration, and using the ANSYS Workbench platform for multiphysics simulation. By performing electromagnetic analysis, fluid and thermal simulations, engineers were able to optimize the oil and water coolant systems simultaneously in less time.

Earlier this year, Volkswagen broke the Pikes Peak Hill Climb record with its Volkswagen I.D. R all-electric racing vehicle. The company developed the car in just eight months. EVs can accelerate quickly, but once the battery heats up, performance falls off. VW solved that problem without adding weight by using air cooling instead of water cooling. VW worked with ANSYS to simulate the virtual drive tests of the entire race to optimize the battery cooling system and aerodynamic drag loss.

Engineers are performing more simulations throughout the



ANSYS simulation tools can be used to measure temperature on battery cells (left) as well as current density. ***Images courtesy of ANSYS.***

design process, and relying on tools that can give them flexibility in fidelity and compute resources. Early work may require faster simulations with lower fidelity as designers settle on the basic vehicle architecture. The fidelity of the models increases as they delve further into the vehicle systems.

Augmented reality is also coming into play when testing these vehicles because of the continued electrification of the human-machine interface. The cabin controls are highly electronic in these vehicles. Newer models use different types of interfaces, like projecting information on the windshield, that also require testing. "In developing these displays and interfaces, there is more of a need to use virtual reality and visualization techniques, light simulation and other approaches," Sovani says.

As more of these highly electrified and increasingly connected vehicles hit the road, they will create a wealth of operational data that can be used to further optimize models and make improvements.

"With vehicles running around the world you have data streaming in," MathWorks' Jin says. "How do you speed up the process of getting from data to insight? We are providing the ability to allow our users to be able to process data as it comes in, running an analytic script using MATLAB on the cloud or in a cluster, and get the information design engineers want."

Greater Focus on EMI, Batteries

There are still a number of emerging needs software providers will target over the next several years so that EV designers can access more functionality. There needs to be improvements in the ability to predict battery life, additional thermal analyses of the batteries as more energy density is pushed through them and availability of more complex functional safety analysis tools, as well as ways to simulate the effects of stresses on the magnetic properties of the motors, according to Sovani.

"There are stresses built on the edges of these components, and those stresses have a significant impact on the magnetic behavior of the materials," Sovani says. "There is a need for in-depth simulation to look at those manufacturing stresses and their magnetic properties."

There will also be a need for more electromagnetic interference (EMI) simulation. "As we move toward autonomous vehicles, that is a need that is only going to grow," LaLande says. "We need to understand how the vehicle will interact with internal and external sources of EMI."

As more start-ups enter the EV market, there will also be more simulation and virtualization of new manufacturing processes, plant configuration, alternative materials and non-traditional vehicle architectures. These newer companies aren't saddled with existing facilities and processes, and will have an advantage when it comes to production innovations.

"They are really pushing the envelope on how to do things differently," Siemens PLM Software's Seeley says. "They don't have to follow the rules that have been in place for 50-plus years. It will be interesting to see how things will evolve." **DE**

Brian Albright *is a freelance journalist based in Cleveland, OH. He is the former managing editor of* Frontline Solutions *magazine, and has been writing about technology topics since the mid-1990s. Send e-mail about this article to de-editors@digitaleng.news.*

INFO ➜ ANSYS: ANSYS.com

➜ **Dassault Systèmes:** 3DS.com

➜ **MathWorks:** MathWorks.com

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

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The Hunt for Invisible Damage

A peek inside the fatigue analysis discipline.

BY KENNETH WONG

IN APRIL, JUST DAYS AFTER the fatal engine failure incident on Southwest Airline flight 1380, the Federal Aviation Administration (FAA) announced its intent to issue an emergency airworthiness directive.

"The directive will require an ultrasonic inspection of fan blades [of CFM56-7B engines] when they reach a certain number of takeoffs and landings. Any blades that fail the inspection will have to be replaced," the FAA stated. The FAA's European counterpart, the European Aviation Safety Agency, also issued a similar notice. The requirements echoed the recommendations issued by the engine manufacturer CFM International.

The culprit for the April 2018 incident was fatigue fracture on one of the fan blades in the engine (the superstitious observers couldn't help but notice it was the No. 13 blade). "There was evidence of metal fatigue where the blade separated," reported Robert Sumwalt, chairman of the National Transportation Safety Board. "The crack was in the interior part of the fan blade, so certainly would not be detectable looking at it from the outside," he added.

In 2016, in another incident involving a separated fan blade in the same engine type, Southwest Airlines flight 3472 made an emergency landing in Pensacola, FL, without any passenger injury. Such incidents give us an idea of the skills and technologies used to hunt for invisible damages in aerospace components.

Lifespan Predictions and Expansions

It might make some frequent fliers uneasy to contemplate the design decisions aircraft manufacturers make, especially the trade-offs between safety and structural efficiency, but it's a reality.

"If you design a structure without any weakness [that is, with sufficient weight, mass and material to address every conceivable failure scenario], then the structure becomes very heavy and overdesigned. So you have to accept some risks," points out Robert Yancey, director of manufacturing production, Autodesk.

Airplane parts, however well-designed, are bound to break down from metal fatigue and wear and tear over time. Therefore, as standard maintenance, parts are inspected at different intervals to verify their airworthiness. The longer a part has been in operation, the more rigorous the inspection.

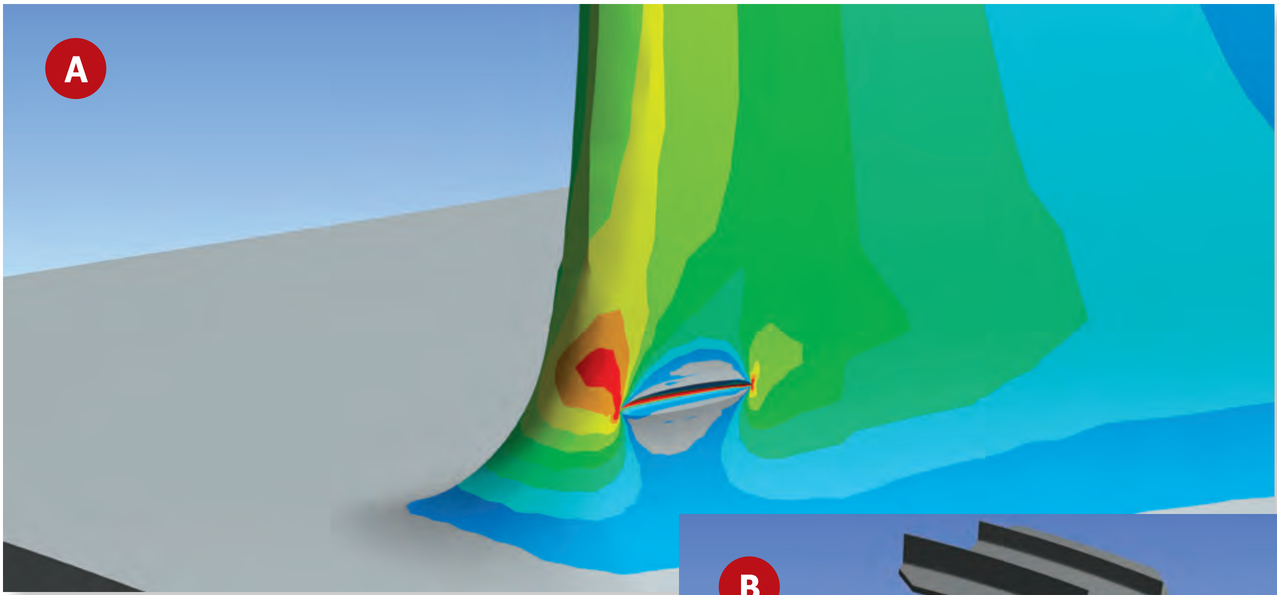
In the early phase of the part's operational life, visual inspections may be sufficient to detect fractures and damages. As the part approaches its twilight, the potential for developing internal deteriorations increases. At this stage, in addition to visual inspections, X-ray, ultrasonic, eddy current and other technologies are employed to examine the health of the part, both inside and out.

Based on inspection results, some parts may be recommended for replacement or repair. In the latter, the intent is usually to extend the life expectancy of the part by implementing features that mitigate sustained damages. As aircraft and parts start showing signs of age, inspection procedures and requirements also get more sophisticated and complex.

When Will it Break?

You can perform a simple fatigue experiment with a paper clip. Take a paper clip, flex it at the same angle and count how many flexes it takes to break. That, in essence, is fatigue life calculation. With parts and components that are much larger, stronger and more expensive, performing the equivalent of this experiment in pixels in simulation software is much more efficient than building a rig to automatically flex or pound the part repeatedly to see how long it will last, or how much beating it can take.

"Fatigue is a mechanism related to the repeated application of cycling loads. Individually, these cycles are too small to cause failure, but added up over time they cause damage and eventually crack initiations," explains Ashwani Goel, senior solution consultant, Dassault Systèmes SIMULIA. "The fatigue failure happens in three stages: The first stage is damage initiation. In this stage the microcracks form and develop.



A: A contour plot of the expected life of a jet engine turbine blade. Red indicates the most critical regions based on the provided loading spectrum.

B: A simulated elliptical embedded crack in a jet engine turbine blade with the stressed region highlighted in red around the crack front. The crack automatically grows during the simulation. *Images courtesy of ANSYS*.

The second stage is the crack propagation. This is the visual lengthening of a crack. The final stage is fracture. This is where the crack has grown large enough in the structure that the remaining load path is no longer sufficient to carry the loading and the part breaks."

"A turbine blade, for example, is expected to survive X number of takeoffs and landings. Engineers can use structural mechanics and CFD (computational fluid dynamics) simulation tools like ANSYS to determine that," says Sean Harvey, technical services manager, ANSYS. Such calculations are reinforced by physical test findings.

"[Fatigue analysis] can be done using a workflow in which internal stresses are predicted with Abaqus [software], then fatigue analysis can be done using FE-SAFE [part of the Dassault Systèmes SIMULIA Portfolio] to predict the number of load cycles until crack initiation, followed by Abaqus again using a low-cycle fatigue procedure to predict the crack propagation and final fracture," says Goel. "This helps identify these types of fatigue related problems not visible to the naked eye. These can address the questions like how long it will take [and where] for a crack to initiate, and then once initiated, how long it will take for the component to rupture."

The Unexpected

Manufacturers anticipate that parts and components will encounter anomalies and unforeseen events. An engine, for example, might ingest a bird or a chunk of ice. "You may not be able to see the damage from an event like this, but you know it takes out a certain number of cycles from its original life expectancy," says Harvey.

"Aircraft are designed with fail-safes so that, even if you miss a crack in a critical component in one inspection cycle, the failure is contained," Harvey adds. Before joining ANSYS, he used to work for a firm that specializes in calculating helicopter blade life expectancy.

To account for these unexpected incidents, "engineers usually put in a safety factor in life expectancy calculations," he says. "If the simulation results and physical tests suggest the part can last 10,000 hours, for example, they may scale it back by 2,000."

One method to respond to unforeseen events is to have good reporting procedures, and to recreate the event—to the extent that's possible—in simulation to recalculate the expected lifespan of the component, Harvey says.

Known Issues With no Easy Answers

Simulation enables the ability to see stress concentration—the general regions on a part that are subject to repeated stress. This

National Transportation Safety Board investigators examine the engine of Southwest Airline flight #1380. *Image courtesy of NTSB.*

identifies the areas vulnerable to stress, but not necessarily the precise point where cracks will initiate.

A crucial part of the inspection cycle is determining when the next inspection should occur, based on the previous inspection results and the part's condition. Misjudging the interval means putting a risky part into service. This is where engineers grapple with the crack propagation dilemmas.

"The inspection is done in such a way to ensure the part is safe to be in use until the next inspection. There are good modeling techniques that let you predict how a flaw in small size will grow over time, over a certain number of flights. That partly factors into deciding when to inspect the aircraft again," Yancey says.

"You want to find the cracks when they're small; you want to catch them before they reach a certain size," says Stuart Brown, managing principal of Veryst Engineering, a simulation and analysis service provider.

Inspection technologies and equipment—such as eddy currents, X-ray and ultrasound—have a resolution limit. "That's the limit of the physical capability of the detection method," says Brown. "So they cannot detect microcracks below their resolution limit."

"If you know there's a crack, you can simulate it. But if you don't know it's there, you won't try to simulate it," says Yancey. Before joining the design and simulation software sector, Yancey held management and executive posts at Aracor and at EWI, firms that specialize in nondestructive testing and evaluation methods.

Simulating the Inspection Methods

Because automotive and aerospace leaders are already investing in digital twins, there may be an opportunity to develop better inspection strategies by conducting virtual inspections along with the physical tests.

"Each inspection method has its own strengths and weaknesses. You can use simulation to check the performance of different methods, to determine which one is best suited for the type of crack or engine part you're inspecting," notes Brown.

Veryst has partnerships with COMSOL, SIMULIA and ANSYS. COMSOL, known for its multiphysics simulation, is particularly suited for certain phenomena. "For example, thermosonic crack detection, which is where you identify cracks by using sound waves to make them heat up," Brown explains. "This technology involves sound propagation and heatwave propagation, so it's a multiphysics problem."

"Simulation methods combining crack initiation and crack propagation analysis methods can provide an invaluable insight into the effectiveness of inspection methods used, for example, to evaluate the condition of engine fan blades in service," says Pawel Sobczak, senior technical specialist, Dassault Systèmes SIMULIA.

Challenges With New Materials

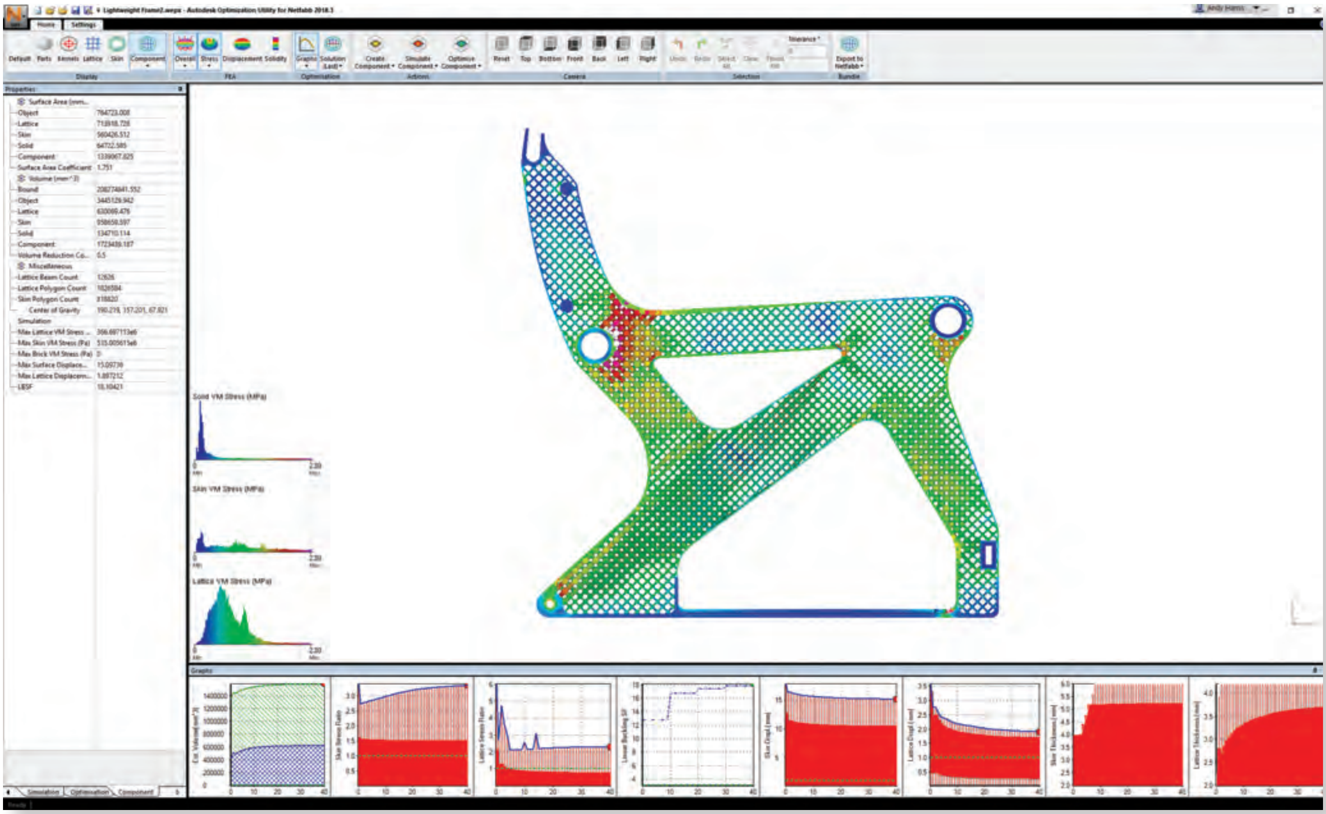
Because of the advantages they offer in lighweighting, composites and polymers from the additive manufacturing (AM) sector are beginning to make their way into aerospace. This raises new questions in fatigue life calculation.

"While we have investigated the characteristics of metals for centuries and therefore have a very good understanding of their behavior, composites and AM not only started to be used on a bigger scale only in the last decade or two, they keep on evolving as the technologies mature," notes Sobczak. "From a designer and engineer perspective, it sometimes feels like chasing an ever-moving target."

"You may know the life expectancy of steel and nickel, but that doesn't mean you can use that to extrapolate how long a steel-nickel-alloy composite part will last," says Harvey. "Companies like Boeing, GE and United Technologies typically have their own material labs, so they can do their own testing, but to qualify a new material [for use in building critical airplane parts] is quite expensive."

"Testing composite materials to qualify them is more extensive, because the materials are not uniform," says Yancey. Classic manufacturing materials such as steel respond to push, pull and stress in every direction the same way. By contrast, composites—made of woven fibers and plies of different materials—respond to forces differently in various directions, depending on the fiber orientation or the ply stack layout. It means the tests required to collect the necessary data to understand their behaviors are much more extensive.

For smaller firms with no in-house testing capacity or financial muscle to quality new materials, the best strategy would be to work with materials that have already been qualified and approved for use in the target industry, such as aerospace or automotive.



This lattice-optimized aircraft seat frame shows relatively even distribution of stress in Autodesk's Nastran simulation software. The small area of heightened stress in red toward the rear of the seat is due to the allowance that the frame can yield at that point under an emergency landing load case. *Image courtesy of Autodesk*.

Better Insights

The sensor-driven internet of things (IoT) technologies are already having an effect on fatigue life analysis. Most aerospace suppliers and manufacturers equip engines and structures with sensors to collect data on the loads on the parts, Yancey notes. The data gives a much clearer picture of part health after each flight.

"Using real-time data related to structural loading and a virtual twin of the engine, it is feasible to follow the fatigue life of the components in the engine in near-real time," reasons Mark Wyatt, senior business development executive, Dassault Systèmes SIMULIA. "This information can be used to inform aircraft operators of needs for additional or accelerated inspection frequencies, for example. Going a step further, the potential of complete failure could be investigated using tools such as Abaqus [or] FE-SAFE."

"The industry traditionally has been on fixed inspection schedules, but it's now moving toward adaptive schedules," Yancey says. "Now that aircraft manufacturers get feedback from sensors, they can develop inspection cycles based on sensor readings to inspect when inspection is required, which saves costs and improves safety."

"If you're talking about an engine blade, ideally you might put sensors on some critical areas to collect values like rotations per minute, vibration and temperature," says Harvey. Previously, this may have seemed impractical, but Harvey believes miniaturized electronics have made it possible. "These readouts can be fed into a digital twin, so you can use the digital twin to compute the component lifespans," he adds.

Yancey believes generative design, an algorithm-driven approach to designing lightweight structures with sufficient durability, could contribute to better, safer parts. "Usually cracks are the result of stress concentration," he observes. "Generative design could help come up with designs that more uniformly distribute the stress loads to avoid high stress spots." Generative design is part of certain Autodesk design software products, such as Autodesk Fusion 360 and Autodesk Netfabb, as well as software from other vendors.

"[Fatigue analysis] has to be a combination of simulation and physical testing," says Brown. "People performing simulation have to obtain feedback from physical tests, and vice versa. It's not a problem that can be solved by one." **DE**

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

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Engineering with Excel

With the right tools and best practices, organizations can move the digital thread forward and keep Excel.

BY BETH STACKPOLE

THE TRIED-AND-TRUE Excel spreadsheet remains an engineering staple despite an eye-popping palette of state-of-the-art technologies, from advanced simulation to product lifecycle management (PLM), each intended to bring efficiencies and productivity gains to design workflows.

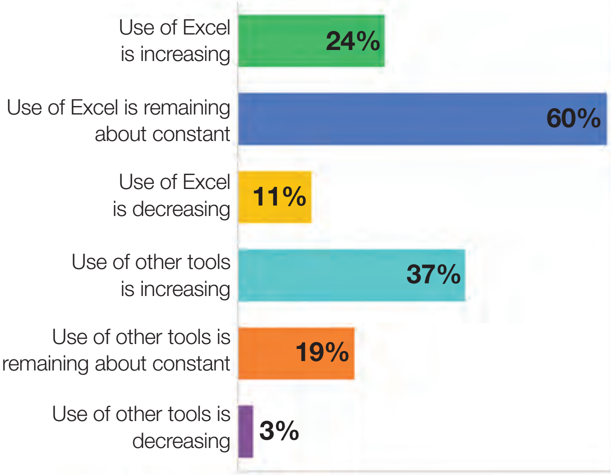
In fact, spreadsheets remain in widespread use throughout the engineering and manufacturing ranks, and there are few signs that usage is abating, according to a recent survey initiated by the NAFEMS Simulation Data Management Working Group, which was also sent to *Digital Engineering* readers.

Excel spreadsheets are extensively tapped by large and small engineering groups as an early concept tool for preliminary design work and engineering calculations, but also for later-stage activities related to engineering-to-order, configuration and pricing.

Specifically, greater than 80% of respondents to the survey reported use of "critical" spreadsheets for engineering design calculations and modeling while 30% tapped Excel for engineering-to-order/configuration-to-order/configure-price-quote workflows. Thirty percent remained heavily reliant on spreadsheets as a data repository.

What was even more surprising was the frequency of spreadsheet use: The vast majority of respondents reported getting their hands on the organization's most critical spreadsheet daily (23%) or weekly (36%). A third of respondents estimated that spreadsheet was accessed by more than 10 people in the organization.

Even with a plethora of new technologies within reach, respondents said spreadsheet use was actively promoted by many in engineering management.



Most NAFEMS and *DE* survey respondents who are using Excel for engineering design calculations and modeling said its use is remaining constant.

Thirty percent of respondents to the NAFEMS survey said their groups were being encouraged to maintain use of Excel as part of the engineering workflow and 84% of those polled expected usage of Excel to either increase or remain constant. Only 11% of those surveyed said spreadsheet usage was on the decline. Another sign of spreadsheets' sustained longevity: The average life expectancy of the most critical engineering spreadsheets was estimated at between one and five years, while more than 35% of spreadsheets kick around and are active for more than five years.

"Excel as a tool in doing what it does best—sorting data, sharing data and doing calculations—is very important and will remain important," notes Tom Maurer, senior director, strategy group for Siemens PLM Software, who cited specific Excel functions such as macros, pivot tables, charts and conditional formatting among the key features that keep the Microsoft productivity tool a go-to workhorse for today's engineering workflows. "But using Excel as a bill of materials (BOM) or a so-called "poor's man's database"—that becomes far more of a challenge."

The Risk of Static Silos

Reliance on Excel spreadsheets within an organization is typically built incrementally, notes Sebastian Dewhurst, director of business development for EASA Software, a low-code development platform for enterprise-grade web apps and a survey co-sponsor. Using Excel for calculations before moving into detailed design and complex geometry makes a lot of sense, he contends, as most engineers are readily familiar with the program already on their desktop as part of the larger Microsoft productivity software suite.

From there, engineering groups may begin to broaden Excel usage for database-type functions, initially dumping a bit of data from a test rig into a spreadsheet and expanding from there until they end up with more than they may have bargained for. "Before you know it, they have lots of big spreadsheets packed full of data and it's not always the best way to do things," Dewhurst says.

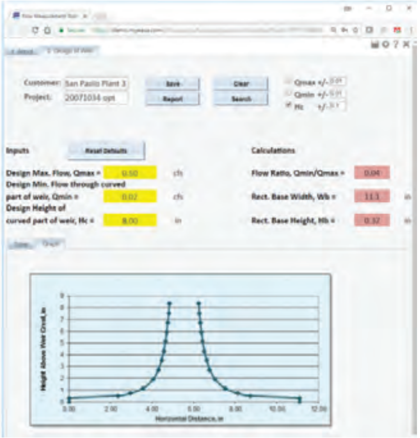
Familiarity with Excel, coupled with its ease of use, give spreadsheets a leg up over product lifecycle management (PLM) platforms, which are often viewed as expensive, less user friendly and typically require significant IT resources to mount a large-scale, enterprise deployment. Excel is good at things PLM isn't—inputting massive amounts of data and easily formatting changes.

"The biggest competitor to PLM is Excel," says Michael Finocchiaro, principal at Finocchiaro Consulting LLC, a PLM consultancy and a technology evangelist. "People have been burned in the past with PLM. That makes it incredibly difficult to deal with the inertia you have to overcome in order to move past the easy way of doing things with Excel."

Yet too much reliance on Excel, especially for data management functions, can open the door to a host of problems, given the growing complexity of product design and the need to engage a greater number of stakeholders in the process, from other engineering functions and among outside design partners and suppliers. Excel can't possibly match the change management and collaboration capabilities afforded by PLM as the software is still an individual productivity tool, and thus manages information in silos.

Although 30% of survey respondents reported using spreadsheets as part of an overall PLM/simulation data management (SDM) process, three-quarters said they had no formal processes associated with spreadsheet use, with most relying on shared network drives or email for collaboration—an indicator there was little to no version control, authentication or security for intellectual property in place. This ad hoc approach to spreadsheet sharing was a definite source of problems—23% said the lack of spreadsheet governance is or could cause major problems.

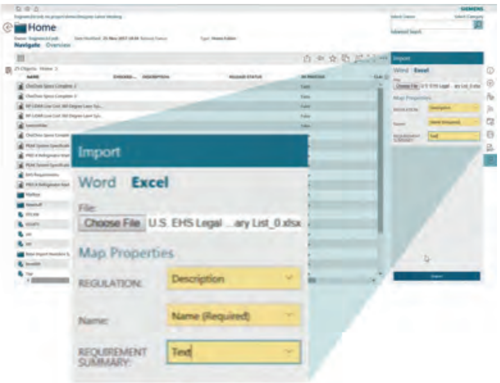
Peter Schroer, CEO of Aras, says he routinely sees Excel being used as a Band-Aid for configuration and database



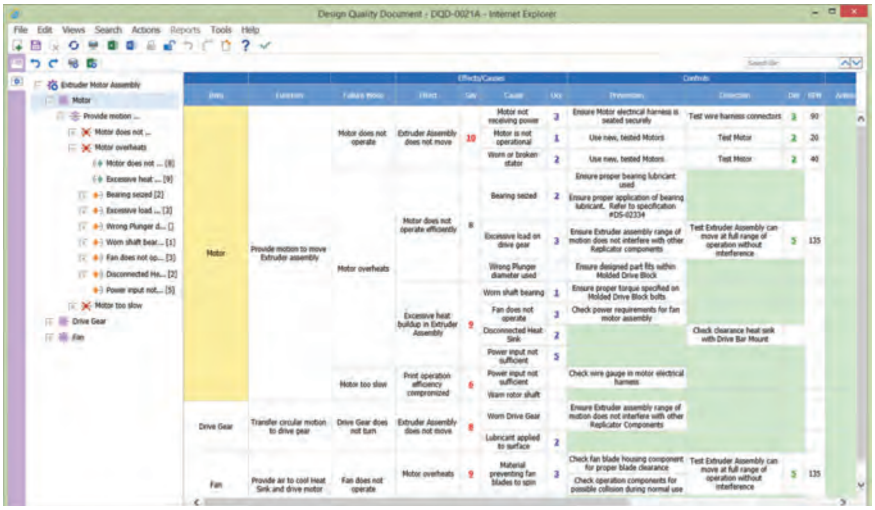
EASA's model deployment platform offers another way to democratize Excel files for engineers without the usual silo or security woes. ***Image courtesy of EASA Software.***

management tasks, but cautions that it's very hard to stay in sync with configuration rules when sales orders and other elements continuously change.

"Using Excel to configure something is not the problem, but using it as a database to store the results of



Siemens has built tight integration between the spreadsheet and PLM, including the ability to map imported Excel columns to properties in Teamcenter. ***Image courtesy of Siemens PLM Software.***



Aras Innovator's Failure Mode and Effects Analysis (FEMA) service has been architected to look and feel like Excel for optimum usability. ***Image courtesy of Aras.***

configuration exercise is dangerous," he explains. "You have different versions of the same file, which purchasing is using to buy parts or quality is using to identify problems on the shop floor. You lack one version of the truth."

On the flip side, Schroer sees a lot of potential for using Excel as part of the simulation workflow, particularly when it comes to the early concept stage, when the goal is quick answers. "Sometimes all an engineer needs to do is run through some stuff in their head quickly and do some math, and Excel is good at that," he adds.

Marrying Excel with PLM

Instead of fighting organizations' desire to keep Excel an active player in engineering workflows, Aras and other PLM providers are doing what they can to create tighter integration and synergies between spreadsheets and their platforms. Aras, for example, has spent a lot of time evolving the user interface of its Innovator platform, in part to challenge Excel's usability and to make it easier for engineers to move tasks over to PLM.

In one such example, the company last year introduced the Failure Mode and Effects Analysis (FEMA) service for Innovator, modeling it to look and behave as if the engineer was still in Excel, Schroer says. "It feels like they are in Excel, but behind the scenes, there is a real database and storage," he adds.

PLM giants Siemens and PTC are also working on tighter integration between their software and Excel. Both offer import and export functions to make it easier to share data between the platforms. More importantly, the integration ensures that what's currently stored and managed in Excel has a pathway to the digital thread that is emerging as engineering organizations move further into leveraging the internet of things (IoT) to achieve a closed-loop digital process for designing, manufacturing and maintaining products.

"When you are taking digital product data and combining it with IoT data to try to do some analytics and look for patterns on feature usage or how well a component is performing in the field, that information is not accessible out of an Excel spreadsheet," explains Mark Taber, vice president, go-to-market and marketing for PTC's IoT Solutions Group. "Excel data is disconnected, it's not part of the thread and is inaccessible. The idea is to make the spreadsheet part of the overall process, and [integration] serves as a bridge to getting people to work inside of PLM."

Dewhurst's EASA Software promotes another way to integrate Excel into the engineering workflow and broader digital thread. Its low-code development platform allows spreadsheets and other models to be deployed as secure web apps that don't expose the underlying Excel file, thus helping to promote information sharing without the common version control and security glitches associated with traditional spreadsheet sharing.

"You are fighting a losing battle if you're trying to stop people from using Excel if it's an appropriate tool," he says. "The next step is to make sure people are using it appropriately." **DE**

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INFO → **Aras:** Aras.com

→ **EASA Software:** EASAsoftware.com

→ **Finocchiaro Consulting LLC:** linkedin.com/company/finocchiaro-consulting-llc/

→ **NAFEMS:** NAFEMS.org

→ **PTC:** PTC.com

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

Evaluate Testing Services

Consider more than cost when choosing a testing service provider partner.

BY JIM ROMEO

AT THE NATIONAL INSTITUTE of Standards and Technology (NIST), scientists and engineers are developing a nanoscale coating for solar cells. The coating, applied with a technique that can be incorporated into manufacturing, opens a new path for developing low-cost, high-efficiency solar cells with abundant, renewable and environmentally friendly materials.

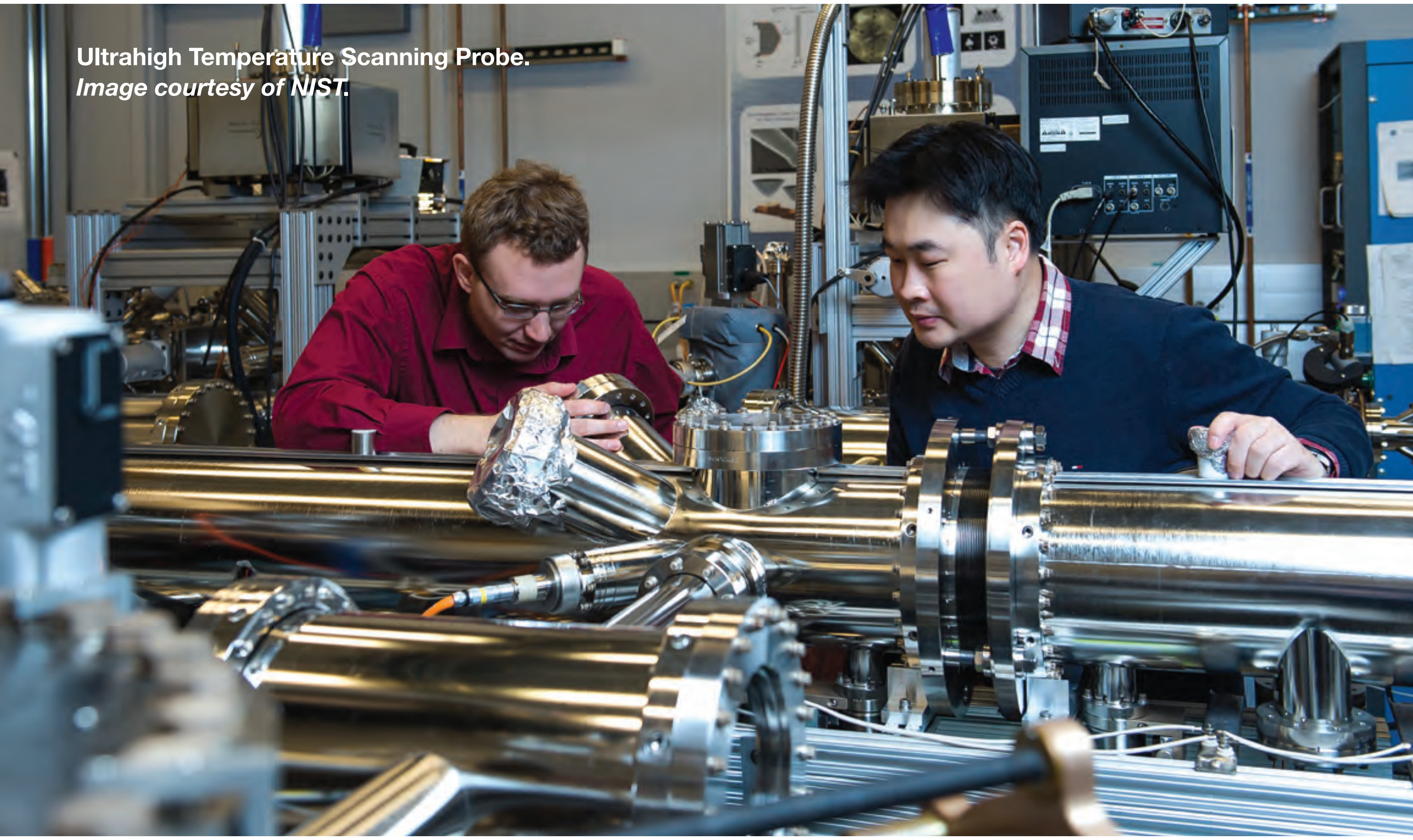
Using laser as a light source to excite individual nanoresonators in the coating, the team found that the coated solar cells absorbed, on average, 20% more visible sunlight than bare cells or uncoated devices. The measurements also revealed that the coated cells produced about 20% more current.

The beauty of science and the merits of engineering design rely heavily on the accuracy and results of testing.

Whether the testing laboratories are simple or sophisticated, engineering design teams rely on the fidelity of labs and service companies that can provide full and reliable testing. However, there are numerous considerations when evaluating a testing service and laboratory.

As new technology is constantly being introduced, labs and their services expand and become more in-depth. Innovation and product development lifecycles are highly dependent on such technologies.

"We all recognize the many societal benefits offered by technology, from cloud computing, big data, machine learning and artificial intelligence, to augmented reality and various types of mobile platforms," says Jay Alexander, senior vice president



Ultrahigh Temperature Scanning Probe.
Image courtesy of NIST.

Measuring nanofilter flow rates.
Image courtesy of NIST.

and chief technology officer at Keysight Technologies, which provides testing and prototype development assistance with software and testing services. "But gaining the full value of these new technologies requires deep expertise across the whole design and test workflow, plus the measurement expertise to effectively implement them."

Understanding what technologies are needed for product development efforts is paramount. Devising a means of evaluating the testing hardware is necessary. But it's even more important to look at the operation of the company, its facilities and its essential processes, then develop an objective way to measure them as a basis for evaluation.

The test workflow, however, has parameters that can be reviewed and monitored in trying to forge the strongest partnership with a testing services company. This means focusing on key areas to evaluate before the prototype goes to the lab.

Response Time

Time to market is always critical for any new product development and product lifecycle discussion. Part of the rubric that aids time to market is getting the best possible grip on the testing vendor's turnaround time.

Testing can sometimes serve as the time period where the product lifecycle may make up ground to make launch dates. Therefore, it's critical to know and understand the average turnaround time of any vendor.

"Engineering and design efforts inevitably take longer than anticipated, yet the product launch date doesn't change, so testing is often expected to make up the difference," says Jared McInelly, engineer solutions director at engineering firm Fresh Consulting. "If you know this, you can plan for it. Utilizing a testing service that can give you accurate turnaround time that fits your schedule is important. Be ready to pay more for quicker turn times—some companies will offer this as a service, and it can be referred to as "next-on-bench."

Cost Considerations

Cost always enters the equation in testing new products and designs. Some test methods can be quite sophisticated and require complex test equipment. Laboratories may require special materials and other supporting equipment to test certain designs. It's important to understand the total cost of testing and what effect it will have on product development cost. This may vary also, depending on the volume of testing conducted.

"Make sure to ask for volume discount breaks," McInelly adds. Large-batch testing allows the vendor to achieve economies of scale; setup time can be amortized across many units, for instance. This lowers the testing service provider's costs. If there are ways to save the testing company money, it's appropriate to ask for some of that savings to be applied.

Capability and Certification

Not all testing services are created equal. Some have calibration equipment, as well as test equipment used for various applications. Depending on what is needed, it's important to survey the equipment capabilities as well as the knowledge base of the company or organization. In the case of NIST's solar cells and their coatings, certain sophisticated test equipment would be required to adequately test and evaluate them to achieve a valuable proof of concept.

Facilities that perform functions such as calibrations often follow certain industry standards. This may be an ISO standard and the equipment and laboratory must be audited, evaluated and certified. Depending on what is needed, it's important to ask questions regarding their certification, who issues them and how long they're valid.

This may also serve as a basis of comparison when evaluating multiple labs or facilities to ensure their practices are comparable.

Management Processes

Another important consideration is the company's management and how it operates. In evaluating a service company, evaluate how many subcontractors they have and how they are used. Myriad other questions may be posed about the way the company handles deliverables, reports and how long things take. It's best to develop a checklist regarding management practices and combine such a list with individual lists related to capability, certification and testing processes.

There's a long list of items to inquire about in evaluating potential testing firms. In general, in selecting a testing services provider, it's important to be aware of any downsides of the firm. "You'll know if they have tested similar products and have experienced the trade-offs and gotchas that come with testing a product like yours," McInelly says. "This kind of knowledge is difficult to make up and their response should give you a solid reading of their true capabilities."

The discussion will also impart the ability to anticipate where testing might be difficult and allow one to better "design for test," saving time and costs.

Understanding the test provider's weaknesses puts companies in a partnership with the test provider, according to McInelly. "You are looking to them for expertise and you are open to their ideas and suggestions," he says. "It opens a dialogue between you and the test provider that can lead to a good, transparent partnership. Things will go wrong and there will be difficult engineering problems to solve as the project progresses."

All told, a testing services company is a critical partner for any design team. It's important to know their infrastructure and their strengths and weaknesses. It will prepare the team and their products for the challenges of the marketplace that lie ahead.

"Having a strong relationship built on transparent and open communication with a test provider is crucial in meeting time-to-market and cost demands," McInelly says. **DE**

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INFO → Fresh Consulting: FreshConsulting.com

→ Keysight Technologies: Keysight.com

→ National Institute of Standards and Technology: NIST.gov

For more information on this topic, visit digitaleng.news.

Developing a Checklist to Aid in Evaluation

Checklists are instrumental in codifying an objective method to fairly and accurately evaluate a testing service and the way it manages and operates. Here is a series of checklists to develop and use in your evaluation process.

1. Certifications required, what they are, for whom they are issued and dates of issue.

2. A list of quality control methods and processes regarding tests and testing procedures.

3. A look at best practices related to accuracy and quality control measures for their test and evaluation methods.

4. A log of equipment, its age, last maintained and calibrated, and how frequently such equipment is used.

5. A checklist that evaluates personnel training and qualifications as it relates to the nature of testing conducted.

6. An examination of audit procedure that the equipment and facility may have to ensure that any internal or external published standards and procedures are met.

7. An objective evaluation of the safety practices used by the facility, including cleanliness and environmental compliance.

8. A means of evaluating customer services, complaints, retention and continued use of the company's services.

9. A list of references who may be contacted and interviewed prior to a contract award or to inquire about the testing company's capability and service.

10. An overall checklist that combines elements of other lists that can be used to, perhaps, provide a quantitative and objective score regarding their service and capability.

Determinism on the Shop Floor

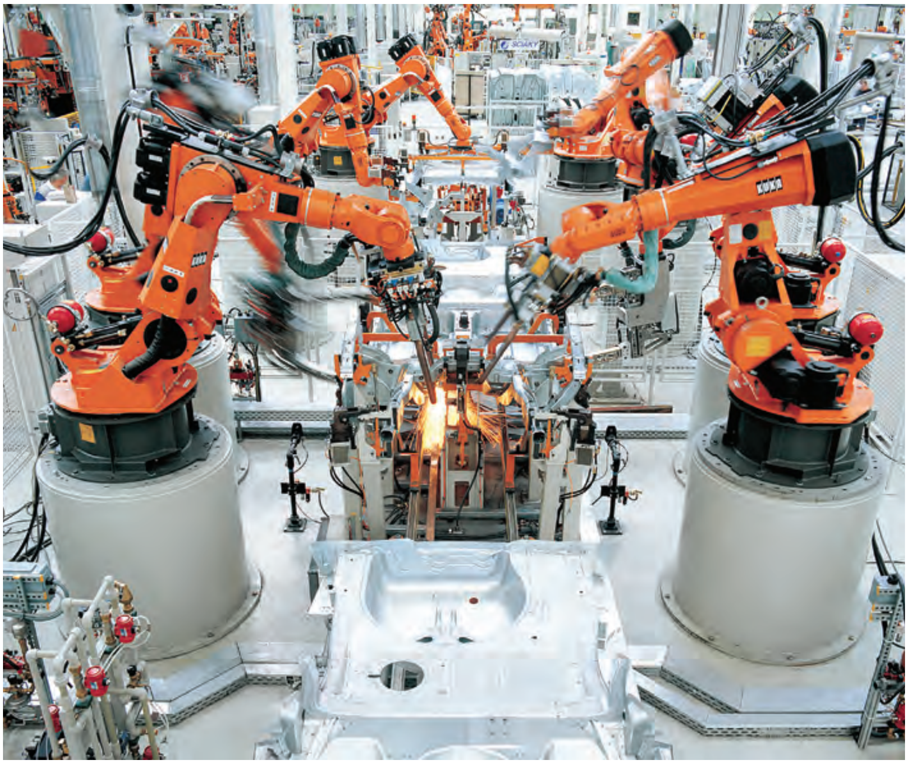
Access to cloud resources enables manufacturers to leverage modern analytics for system optimization and predictive maintenance.

BY TOM KEVAN

UNTIL RECENTLY, COMMUNICATIONS technologies like Ethernet and OPC Unified Architecture (UA) have experienced limited success in supporting complex industrial processes with real-time requirements. This, in turn, has restricted the applications that discrete and process manufacturers could adopt. New developments, however, promise to address these shortcomings.

In March, the OPC Foundation released the Publish-Subscribe (PubSub) extension of the OPC UA standard, aimed at pushing communications enhancements to controllers, sensors and embedded devices at the deepest levels of the shop floor. Concurrently, the IEEE has extended the Ethernet, providing for deterministic communications through a set of IEEE 802 standards that enable time-sensitive networking (TSN).

Industry technology developers contend these steps will provide the building blocks required to create a holistic communications infrastructure tailored to better meet the needs of the industrial internet of things (IIoT). By combining PubSub and TSN with OPC UA and standard Ethernet communications, they aim to deliver deterministic performance, improved quality of service and solid security while maintaining broad interoperability among third-party devices and systems.



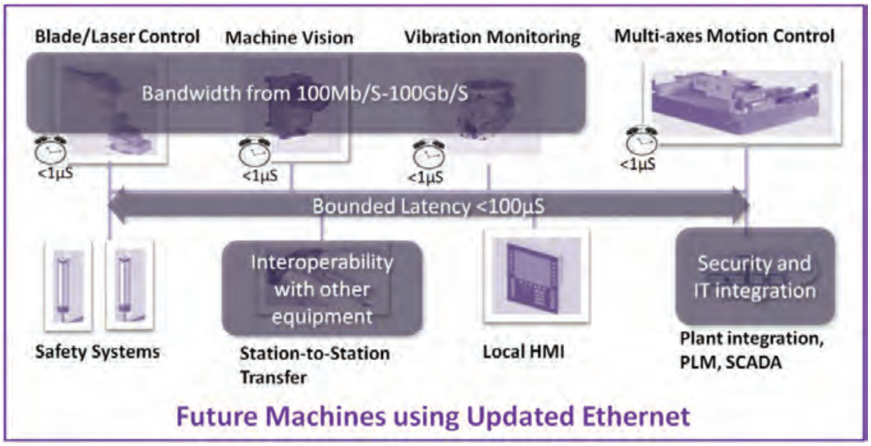
Time-sensitive networking and the OPC UA Publish/Subscribe model have come together to deliver strict and dependable real-time communications, enabling an expanded array of demanding applications on a single physical network. *Image courtesy of Avnu Alliance.*

Adding PubSub

A key element of this technology mix, PubSub, homes in on issues arising from the IIoT's emergence and the consequent explosive growth of devices and data serviced by automation networks. This technology seeks to provide a more efficient, uniform model for distributing data and events within production environments.

Until recently, the standard model for devices communicating on an industrial network was the request-response, or client-server, paradigm. Using this approach, a client device (e.g., human-machine interfaces) requests data or services, and a server (e.g., programmable logic controllers or programmable automation controllers) responds to those needs.

The catch here is that each client must open a direct connection with the server. As the IIoT takes shape and the amount of data generated at the machine level grows, network performance can degrade, hindering or precluding certain control functions.



A broad cross-section of the networking industry has come together to update standard Ethernet, creating a communications infrastructure tailored to deliver deterministic performance, improved quality of service and broad interoperability among third-party devices and systems. ***Image courtesy of Avnu Alliance.***

"The client-server communication model puts a strain on the server, or the producer of data, because each client initiates a separate transaction with the server, and this strain grows with the number of clients," says Abdul Jabbar, senior researcher in the edge computing group at GE Global Research. "In industrial controls, the servers of data are also critical to machine operation. This poses a problem. If hundreds of clients request their own copy of the same data, the controller can become overloaded serving these requests."

The PubSub model alleviates this problem by using a central source called a broker, or server, to act as a data clearinghouse. Clients can publish data to the broker or subscribe to data from the broker, or both.

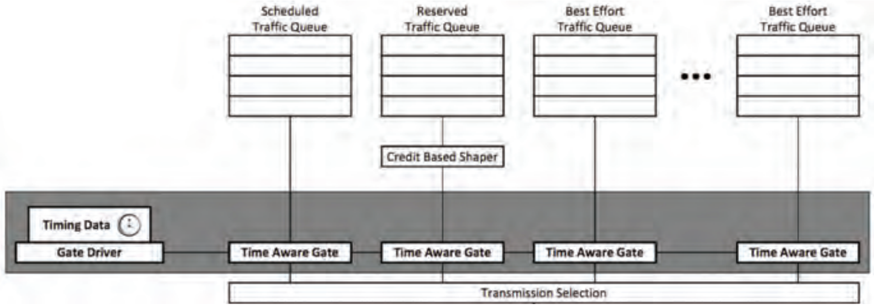
With PubSub, the network defines a fixed time window in which clients and brokers exchange data. The model eliminates point-to-point connections, relying solely on multi-point links via user datagram protocol. This relieves the broker of individual client requests. Instead, the broker publishes each dataset once. This reduces the workload of controllers and cuts network traffic, and enables smaller embedded control devices that lack resources for typical client-server transactions to publish.

PubSub further reduces network traffic by supporting transactions that only contain data that has changed since the previous data transfer. Clients and brokers transmit data only when the content has changed. This avoids repetitive blind requests and data transfers that ensure the acquisition of the most current data. Compared with the request-response model, the number of connections decreases, and they are replaced by a lightweight link for each client-to-server connection. This link remains open and carries only two types of messages: changed data and a tiny heartbeat that tells the broker that the client is still present. The broker does not store data, it only moves it from publishers to subscribers.

The PubSub model sets the stage for deterministic network performance. "The publish-subscribe model, in and of itself, does not enable deterministic communications," says Jabbar. "However, since the data transmission from publishers is quantized through datasets and relatively stable/static over time, it is well suited to deterministic networks, which require predefined data flows."

In addition, PubSub provides a foundation for OPC UA TSN. "The Publish Subscribe extension for OPC UA is now available in release-candidate form, enabling the exchange of OPC UA over UDP connections," says Ludwig Leurs, director of Ethernet convergence at Bosch Rexroth, which is a member of the Avnu Alliance. "This is the prerequisite for running OPC UA TSN."

The bottom line: PubSub makes sense for the IIoT. It efficiently and reliably moves data among several sources and destinations on the plant floor and allows for direct and seamless integration with modern cloud platforms. Access to cloud resources enables manufacturers to leverage modern analytics for system optimization and predictive maintenance.



Time-aware traffic scheduling precisely coordinates data transfers across the network, enabling scheduled transmission for given classes of traffic across a TSN-enabled network. *Image courtesy of Avnu Alliance*.

Picking up Where PubSub Leaves off

The PubSub model defines communications patterns among devices. It does not dictate how data transmission occurs. When a data frame traverses a network switch on the way to its destination, it can encounter traffic on the egress port, leading to buffering and variable delay, breaking the key tenant of real-time communications. TSN addresses this by providing automation and industrial control applications with a system to ensure consistent data delivery from sensors to controllers and actuators.

"TSN ensures that specific traffic is delivered in a timely manner by securing bandwidth and time in the network infrastructure to support coexistence of critical and non-critical forms of traffic," says Paul Didier, IoT solutions architect at Cisco Systems and Industrial Internet Consortium liaison. "This enables users and vendors to derive benefits from increased connectivity to more devices over a single, standard physical network, enabling services such as VoIP, video, telemetry, analytics and critical control to share the same network."

To enable these advances, TSN relies on three key features. These include time-aware scheduling, synchronization and frame pre-emption. When combined, these features enable precisely timed transmission of data throughout its path, from source to destination, which is the essence of deterministic communication.

Getting in Sync

A core component of TSN is a common sense of time. Deterministic communication requires timed transmission of data. This, in turn, demands that all network elements have synchronized clocks. In the absence of an out-of-band synchronization mechanism (e.g., GPS) on all nodes, IEEE 802.1 AS provides a mechanism that enables time synchronization.

The specification does this by standardizing the precision time protocol, the working clock used to drive measurement and control functions on end stations, synchronizing the operation of controllers, sensors and actuators with the rest of the system.

System-wide time synchronization makes it possible to schedule transmissions and coordinate traffic with the network to ensure the highest quality of service. In the process, it pushes network performance toward faster motion control and testing, as well as greater quality assurance. TSN devices available on the market can achieve time synchronization within 10 nanoseconds with hardware timestamping.

"When all the parts of a network are running with the same sense of time, traffic can be coordinated based on a schedule, allowing for precise time synchronization and better control of critical traffic types," Didier says. "With TSN, the scheduled critical traffic is guaranteed, and the non-mission-critical traffic can coexist without disrupting the delivery of the critical traffic."

Time-Aware Scheduling

When working with IEEE 802.1 AS, the time-aware shaper plays a key role in enabling the creation of truly deterministic networks. Once it is implemented in a network end point or switch, 802.1Qbv operates a gate on every queue of an egress port, providing the network configuration manager with the ability to control the gate state (open or closed) with a schedule.

Time-aware gates immediately precede a bridge's transmission selection function. Each transmission gate corresponds to a traffic class associated with a specific queue, with potentially multiple queues associated with a given port. A configurable gate control list determines whether a traffic class' gate is open or closed at any point in time, and the gate control list is executed over a configurable cycle of time.

"Real-time communications imply that data is transferred from the source to the destination instantly, without delay," says Jabbar. "Ideally, this means the latency is simply bounded by the physics of data transmission and propagation, with no additional delay. With TSN's time-aware scheduler, it is possible to precisely time the gate state at each network hop in between the source and destination in such a way that a data frame experiences no additional delay or buffering. For example, some switches can control the transmission of a frame within a bound of 100 nanoseconds."

This kind of traffic control provides all data transmissions with the level of service required. "An industrial control application can minimize latency and path delay variation for control traffic by configuring the gate control list so that high-priority control traffic will transmit at known time intervals," says Didier. "Similarly, gate operations for lower priority, or best effort, traffic can be allocated in the gate control list to time slots not used by high-priority control traffic, ensuring that all traffic types will flow."

Frame Preemption

With time synchronization and time-aware scheduling, it is possible to control gate states (open/close) at each network element. This should lead to precisely timed transmissions and therefore deterministic communications—except for one issue: Ethernet is a store-and-forward network. If a frame begins transmission just before the start of a time period reserved for a high-priority transmission, it can extend the lower priority transmission outside its allocated window, potentially interfering with more critical traffic. Therefore, a guard band (an unused portion of the frequency band) equal in size to the largest possible interfering frame must be added before the window starts.

By using the frame preemption feature defined in IEEE 802.1Qbu and the related physical layer standard interspersing express traffic (802.3br), the network avoids this kind of delay by pausing the lower priority transmission, executing the scheduled transmission of the high-priority frame at the predetermined time, and later resuming the lower priority transmission.

Frame preemption does this by breaking the interfering frame into smaller fragments and inserting a guard band between the two competing transmissions. In this case, the guard band need only be as large as the largest possible interfering fragment instead of the largest possible interfering frame, which would be a less efficient use of network bandwidth.

Frame preemption's contribution to greater network efficiency, however, doesn't stop there. Industrial automation applications, such as machine control, typically take the form of long line configurations. To minimize wiring cost and complexity, a typical installation uses a daisy-chain configuration, where each node has external switched ports and an internal port that goes to the end node. Operating under these conditions, the accumulated latency per hop becomes problematic. Frame preemption mitigates this problem by minimizing the frame delay at each hop.

New Design Tools

Looking at the synchronization, time-aware scheduling, and frame-preemption features, it becomes apparent that the TSN standards were created with a system view in mind, rather than a component perspective. Scheduling becomes more calculable from a mathematical perspective, allowing system designers to determine in advance if the network will be successful.

"This dramatically changes the workflow for designing and planning networks," says Didier. "TSN values network calculus and planning as part of the solution toward managing traffic and guaranteeing performance. In this new paradigm, payload, sampling frequency and maximum latency can all be managed from a system-wide view to calculate flows and configure bridges and infrastructure to meet these demands."

This holistic approach to network design requires new tools, with new operating parameters. For example, National Instruments, Cisco and Intel have collaborated on an early-access technology platform for TSN that enables developers to more quickly build distributed systems using TSN. The platform can be used to perform synchronized input/output, code execution and deterministic communication for distributed control and measurement loops, all using standard Ethernet.

One of the remaining challenges in realizing deterministic communications entails the task of scheduling and configuration. Because TSN requires timed data transmission at every hop between source and destination, a schedule must be computed for gate control of every queue, on every port, for all elements in the network. This scheduling problem is equivalent to a NP-complete graph-coloring problem, which makes finding a feasible schedule difficult. Furthermore, TSN configuration involves predefining data flow requirements and setting up gate schedules in all network elements.

A number of companies offer tools to simplify these tasks. One of these is TTTech's network scheduler Slate XNS, a browser-based software package that promises to streamline topology modeling, schedule development and TSN network configuration. The company contends the software's graphical user interface enables offline network configuration, which provides a topology view or table-based editor for managing components and data streams.

Another development offering is GE's TSN Toolset, which combines flow requirements acquisition, schedule generation and device programming in a single toolset that can natively integrate with industrial applications.

Through TSN's methods of modeling, system designers can proactively answer questions about their network's capability before the system is integrated, and plan for the traffic that needs management. If designs prove inadequate or a solution is not achievable given system constraints, then network design can be modified to accommodate the system requirements. **DE**

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

INFO ➜ Avnu Alliance: Avnu.org

➜ **Bosch Rexroth:** BoschRexroth.com/en/xc

➜ **Cisco Systems:** Cisco.com

➜ **GE Global Research:** GEGlobalResearch.com

➜ **Industrial Internet Consortium:** IIConsortium.org

➜ **Intel:** Intel.com

➜ **National Instruments:** NI.com

➜ **TTTech:** TTTech.com

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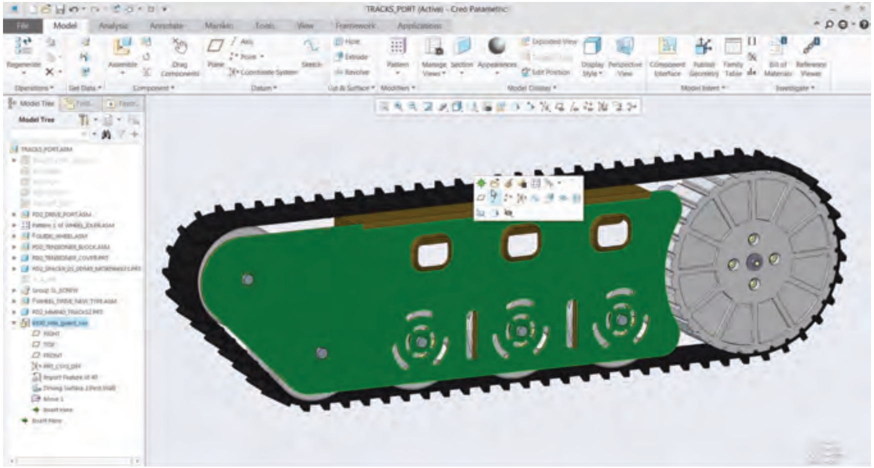
PTC Creo 5.0: New and Improved

The latest release offers new features and a wide range of extensions.

BY DAVID COHN

FIRST THERE WAS PRO/ENGINEER. PTC launched the world's first parametric, associative feature-based solid modeling software 30 years ago. In 1998, PTC Windchill ushered in the age of internet-based product lifecycle management software. Then, after acquiring CoCreate in 2007, PTC set out to integrate that program's direct modeling technology with the parametric functionality of Pro/ENGINEER. The fruit of that labor was the launch of PTC Creo in 2010. Since then, the company has issued a major update approximately every two years. PTC Creo 3.0 made its debut in July 2014. Version 4.0 came out in December 2016. Now we have Creo 5.0.



PTC Creo 5.0 features a modern interface, with a contextual ribbon and mini toolbars. ***Images courtesy of David Cohn.***

PTC announced Creo 5.0 in March, the latest release of the company's flagship design and engineering CAD software. This new version introduces updated toolsets and enhanced features throughout, including new capabilities in the areas of topology optimization, additive and subtractive manufacturing, computational fluid dynamics (CFD) and CAM.

Pro/ENGINEER had a reputation for being expensive and difficult to use. That characterization has definitely changed. Today, a basic Creo license costs around $2,000, although adding multiple extensions can certainly increase this dramatically. Getting started with Creo is also much easier than ever before. Download a 30-day free trial of Creo Parametric 5.0 and start learning to use the software, aided by an online tutorial complete with sample files.

PTC has continued to update the Creo user interface (UI), which now provides a more modern appearance. Like other Windows programs, the Creo UI now includes a Quick Access Toolbar and context-sensitive ribbon tabs across the top of the screen. There are also mini toolbars within the graphics window. For example, when selecting an edge in the model, a mini toolbar provides options for operations such as editing dimensions, adding a chamfer or round, and other functions.

A navigation panel with tabs for the Model Tree, Folder Browser and Favorites is located along the left side of the screen and a status bar and selection filter appear along the bottom. You can toggle the navigation panel on and off, and open a browser window within the graphics area. When expanding and collapsing the Model Tree, and when selecting an object in the model, it highlights in the Model Tree and vice versa.

You can switch to a full screen mode, which enlarges the graphics area to fill the entire screen, with no other UI elements visible other than the mini toolbars. Yet, when moving the mouse to the top of the screen, the ribbons reappear to select an operation. Press F11 at any time to exit the full screen mode.

Core Updates

The latest version—PTC Creo 5.0—offers a number of core modeling enhancements, including easier application of draft features to geometry that includes rounds. For example, once selecting the surface to which to apply draft, the software will remove the rounds, apply the draft and then automatically reattach the rounds. It's not necessary to split faces, because Creo's draft operation has an option to use a mid-plane.

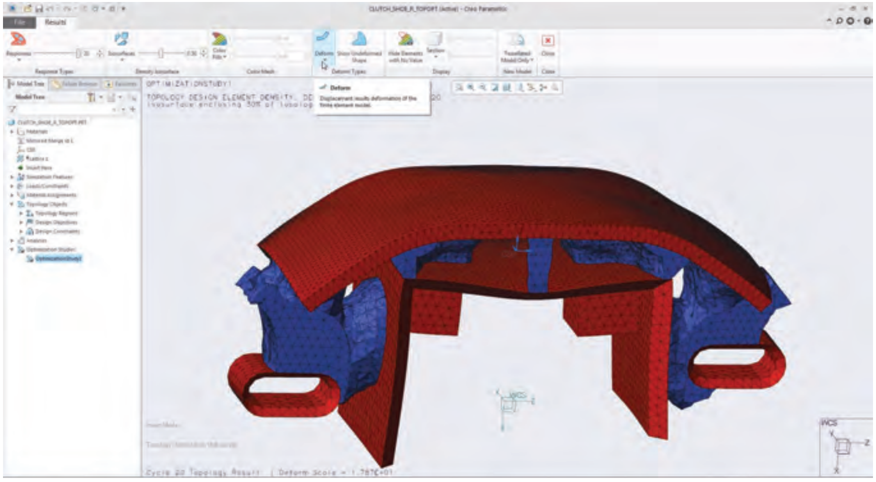
The new helical sweep tool enables users to create accurate 3D geometry of parts machined with cutting tools. You can specify a revolve profile and a helical trajectory along which to sweep the profile. This new capability has many applications, such as for cams and complex threads.

With Creo 5.0, you can work in orthographic or perspective mode and easily toggle between them. Sketch regions allow you to create a single sketch with overlapping geometries and then select multiple closed regions to extrude or revolve.

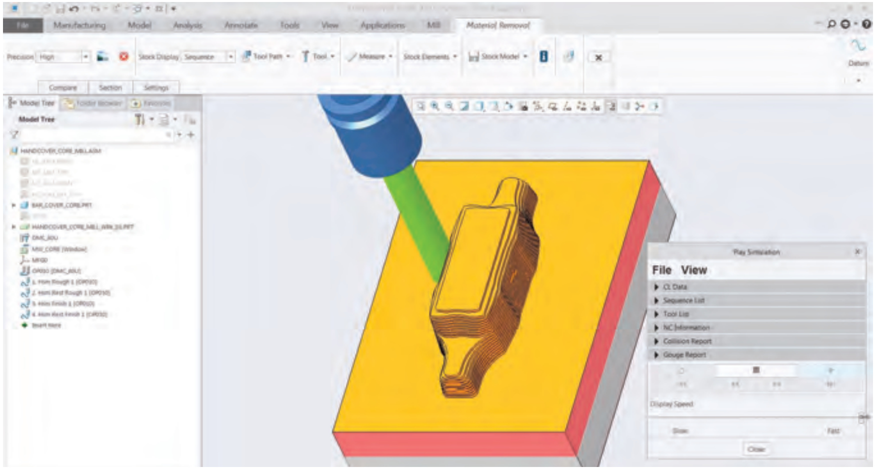
The program's sheet metal capabilities have also evolved. The latest release introduces two corner relief types with explicit control over orientation. You can use a flat state representation of a component and store it as part of the design model. The software also lets you switch between the bend and flat state in either an assembly or in a drawing.

Essentials and Extra Extensions

The core Creo software—Creo Parametric Essentials—meets the needs of most users. It includes 3D part and assembly design, automated 2D drawing creation, multi-CAD data exchange, parametric and freestyle surfacing, assembly management, sheet metal, mechanism design, plastic part design, structural framework and weld design, realistic rendering and animation, direct modeling, basic part analysis, fastener design, 3D printing and augmented reality (AR).



Topology optimization automates the creation of optimized parts, creating the right design based on objectives and constraints.



The mold machining extension generates optimized toolpaths for the creation of molds, tools, dies and electrodes. When designs change, toolpaths update.

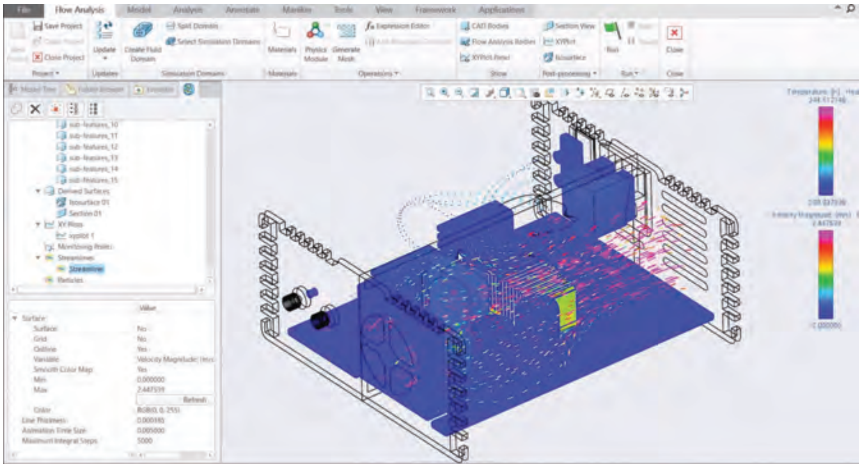
Essentials Plus adds revision control and vaulting of product data. Essentials Premium incorporates all the Essentials and Essentials Plus features, and adds structural analysis for parts and assemblies, motion analysis, pipe/tube design and cable/wiring design.

For those needing even more advanced capabilities, PTC offers myriad extensions to handle design tasks such as free-form surfacing, simulation, photorealistic rendering, additive manufacturing and connections to PLM systems. Many extensions are updated in this latest release.

For example, the new Creo Topology Optimization Extension automatically creates optimized designs based on a defined set of design criteria, goals and objectives. The software uses analysis to help engineer an optimal design while considering optimal fabrication constraints. The basic version of this extension handles symmetry, extrusion and filling constraints, as well as structural and modal analyses, while Creo Topology Optimization Plus adds additional fabrication constraints (such as stamping and radial spokes) and thermal analysis.

Creo's additive manufacturing capabilities enable users to create parametrically controlled uniform or variable lattice structures. When combined with simulation, users can optimize the lattice structure to solve multiple design requirements simultaneously. Core capabilities enable printing directly to various plastic/polymer printers.

Creo 5.0 also introduces the Creo Additive Manufacturing Plus Exten-



Creo Flow Analysis provides CFD integrated directly in Creo, enabling users to do fluid flow and heat transfer simulations.

sion for Materialise, which extends the program's additive manufacturing capabilities to include metal parts, enabling users to print production-grade parts directly from Creo and to connect to the Materialise online library of print drivers and profiles. Creo's CAM capabilities extend from two- to five-axis machining, and include multi-path machining, NC post-processing and more. The new Creo Mold Machining extension generates optimized toolpaths for the fabrication of molds, tools, dies and electrodes, for any situation in which low volume, geometry-based numerically controlled programming is required. And because all of Creo's CAM capabilities are fully integrated, when the design changes, so do the toolpaths.

The Creo Flow Analysis extension is a CFD solution that allows designers, engineers and analysts to simulate fluid flow issues directly within Creo. The seamless workflow between CAD and CFD allows users to integrate analysis early in the design process so they can better understand product function and performance.

The software has multiple analysis options, including internal and external flow, heat transfer and turbulence. PTC also offers advanced packages for those users who need more powerful simulations, such as cavitation and multi-phase. The Creo Collaboration Extension for Autodesk Inventor enables bidirectional exchange of parts and assemblies with Autodesk Inventor. Other extensions enable customers to use a model-based definition approach to design and to connect their models to PLM systems.

Other Tools Included for All

Every seat of PTC Creo includes AR capabilities. Users can publish an AR experience of a model and then they can visualize it through PTC's free ThingWorx View app. The free tool enables the ability to publish up to five models at a time to the ThingWorx Experience Service, where access is open to anyone who knows the link. A Premium account controls access for AR publishing, sharing and viewing.

Every package also includes Creo's Human Factors Design tools, which let users quickly insert and customize digital human models to study ergonomic issues, such as human reach and vision. An eLearning Library provides more than 140 hours of training. When users need to work remotely, they can borrow a floating license for up to 180 days. Every package also includes a home use license of the Creo Parametric Essentials package. And the Creo Performance Advisor provides a dashboard for the entire Creo installation, allowing users to understand and optimize system performance.

Links to download a free 30-day trial of Creo Parametric 5.0 are easy to find on the PTC website. But don't bother searching the site to learn how much the software will cost once that trial expires. For that, contact PTC or an authorized reseller. The same is true regarding pricing of the many Creo extensions, or any other PTC software.

PTC and Creo have certainly come a long way in 30 years. After revolutionizing mechanical design with the introduction of Pro/ENGINEER, PTC continues to push the envelope, combining digital design, engineering, simulation and manufacturing with a very extensive product lineup. **DE**

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

INFO → PTC: PTC.com

PTC Creo 5.0

PRICES

- Prices start around $2,000 per seat per year. Enterprise and extension prices available on request.

SYSTEM REQUIREMENTS

- **Operating System:** Windows 10, Windows 8.1, Windows 7
- **Memory:** 3GB RAM (4GB or more recommended; 32-bit OS can only access 3GB of RAM)
- **Monitor:** 1280x1024 (or higher) resolution with 24-bit or greater color
- **Graphics Card:** For 3D hardware acceleration, an OpenGL graphics card must be used that has been tested in a PTC-certified configuration.
- **Pointing Device:** Microsoft-approved three-button mouse
- **File systems:** NTFS

Autodesk Nastran In-CAD

Walk through the setup and analysis of a simple bracket to get an overview of this CAD-embedded finite element analysis software.

BY TONY ABBEY

A FEW YEARS AGO, Autodesk acquired NEi Software, a small company that developed an independent finite element analysis (FEA) solver that closely emulated the traditional Nastran input and output structure. Since then, Autodesk has embedded much of the solver technology into its Autodesk Inventor environment as Autodesk Nastran In-CAD. The full solver capability also continues to be available as a standalone product, Autodesk Nastran.

For this review I have created a simple bracket model. The file is available for download at digitaleng.news/de/autodesknastran. Versions using Parasolid, Autodesk Inventor and SOLIDWORKS formats are available. The Autodesk Nastran input files and result files are also available for download.

User Interface

Fig. 1 shows the Autodesk Inventor user interface (UI), with the bracket geometry shown. The layout is traditional, with a tree view, graphics area and a main menu running horizontally across the top. Autodesk refers to this as the ribbon. Selecting a tab on the ribbon opens a set of commands and drop-down menus. Fig. 1 shows the Tools options selected.

I opened the Parasolid version of the geometry and was interested to see how the geometry conversion was handled. The source file holds the default input units, which in this case picks up meter units. This can be changed to inches easily. However, it is always a good idea to check units and dimensions during an

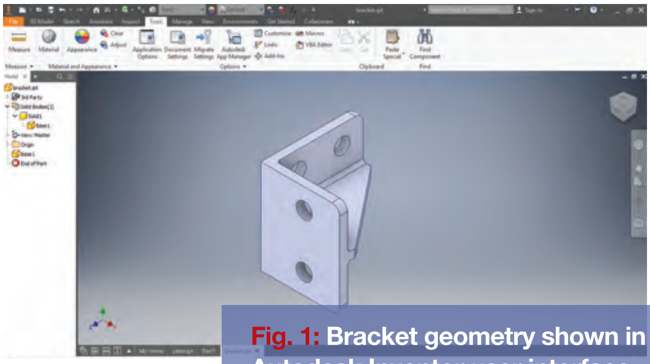


Fig. 1: Bracket geometry shown in Autodesk Inventor user interface. ***Images courtesy of Tony Abbey.***

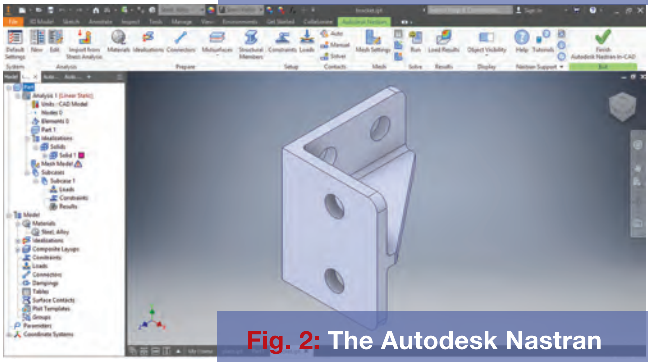


Fig. 2: The Autodesk Nastran In-CAD ribbon and tree view.

import. The Inspect tab has an easy-to-use measure tool, which is always a good check. The vertical bracket edge is correctly reported as 2.75 in.

Users can check model units by using Document Settings under the Tools tab. The units are reported as inches and pound mass. I was a bit skeptical as to whether strict mass units were being used. I was carrying out a dynamic analysis, so it is important to be clear on this point.

Editor's Note

This is the latest in a series of review articles looking at FEA software products. Each overview is formatted as a walkthrough using a simple structural example. The full capabilities of each product cannot be covered in a few pages, but the hope is to provide a feel for the basic workflow required for each product.

Each of the walkthroughs represents Abbey's independent assessment and is not sponsored in any way by the companies developing the products. However, in many cases he is indebted to the companies for supplying temporary licenses to allow the overviews to be completed.

I selected alloy steel from the provided material list. It is also straightforward to set up a new material library or define a new material. The file created is clearly indicated and can be copied or made centrally accessible.

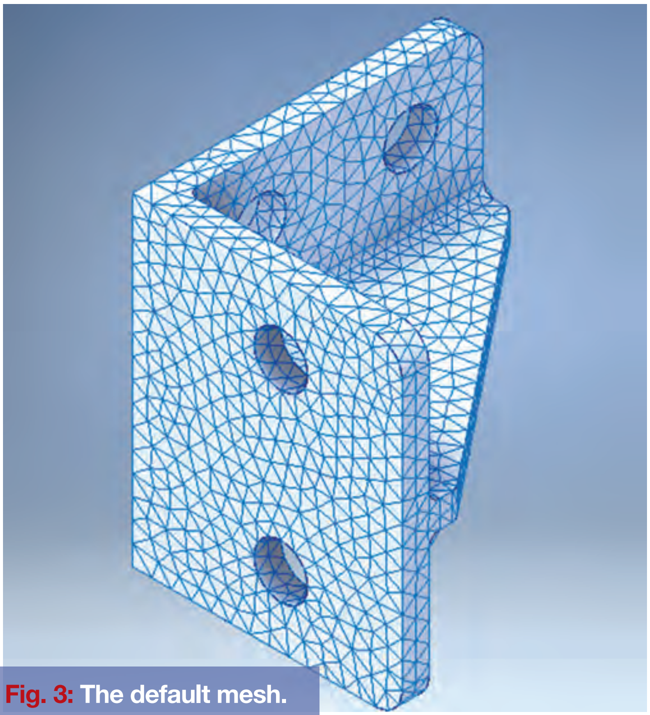


Fig. 3: The default mesh.

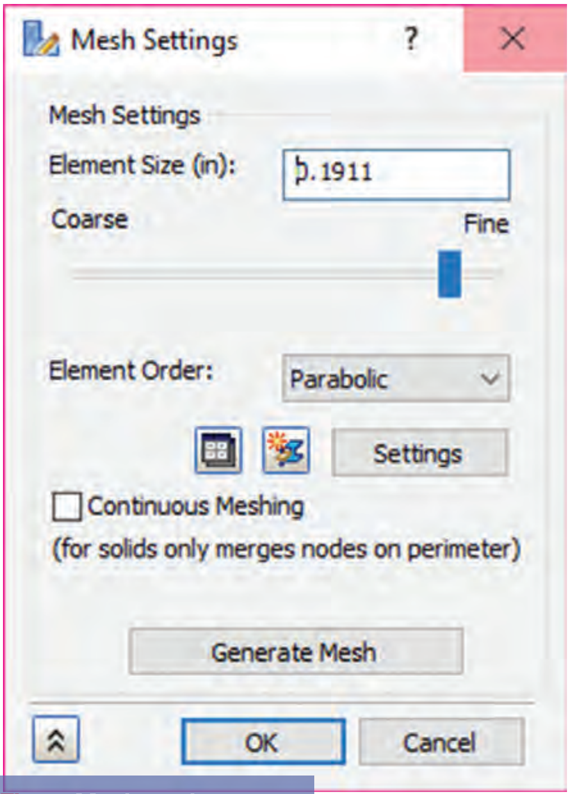


Fig. 4: Mesh settings.

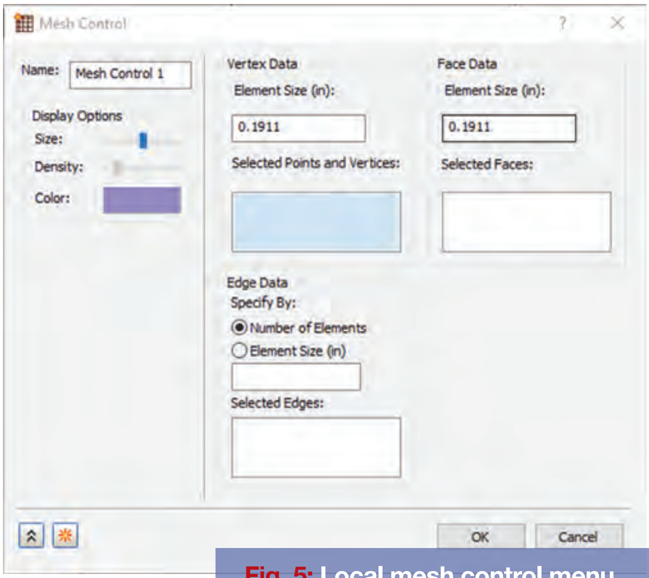


Fig. 5: Local mesh control menu.

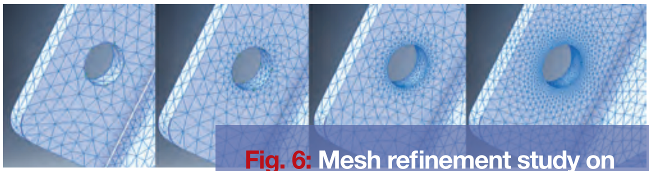


Fig. 6: Mesh refinement study on bolt hole region: from left to right 6(a) default mesh, 6(b) element size factor 0.5, 6(c) element size factor 0.25, 6(d) element growth factor 1.2.

Right mouse-clicking on the Solid1 object in the part tree view allows the body properties to be listed. The results are a 'mass' of 1.279 units and a volume of 4.578 cubic in. This confirms that the Autodesk material is using a weight density and that this is the weight of the part. The simulation tool is selected by using the Environments tab and then the Autodesk Nastran In-CAD icon. A new ribbon and tree view appears as shown in Fig. 2.

Tabs appear that cover the usual FEA actions of pre-processing, analysis control and post-processing. The new tree view is in two sections: the Analysis tree that shows the options applied to the current part for this analysis and the model tree that shows all the options that can be set. The options defined in the model tree are available for use in the Analysis but are not activated until dragged across or created directly from within the Analysis tree.

The solid geometry present has spawned a 3D solid "Idealization" object, as shown in Fig. 2, with inherited part material properties. There are two other Idealization options that can be associated with the model using 2D shell elements or 1D beam elements. The 2D shell option requires surfaces to be designated for meshing. There are three possible approaches: automatic creation of Thin Bodies, Mid-surfacing and Offset Surfaces. Thin Body creation uses a criterion of 20:1 for length to thickness. The bracket is too "chunky" to pass this test and so no automatic surfaces can be created. Mid-surfacing attempts to create mid-surfaces through the solid body. Offset surfacing allows external body surfaces to be copied to an interior posi-

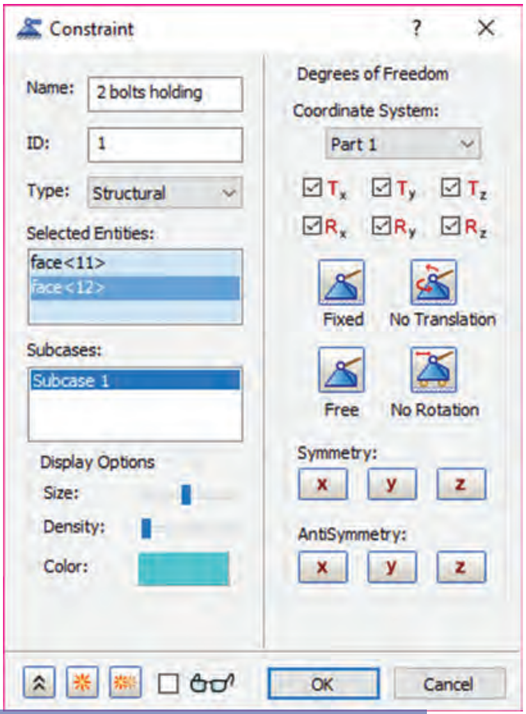


Fig. 7: Constraint definition.

tion via an offset. Experimenting with both methods resulted in a gap between the bracket faces and the central gusset. A more general approach would be to create the required surfaces directly in Autodesk Inventor. 1D beam elements can be meshed from Autodesk Inventor Frame Members.

Meshing

Fig. 2 shows a warning that a mesh is required. Right-clicking on Mesh Model or using the ribbon icon generates the mesh. The result is shown in Fig. 3. Right-clicking on the Model Mesh or using the ribbon icon accesses the mesh settings shown in Fig. 4.

The default or global mesh size is 0.1911 in. This is a very useful parameter, as it indicates the starting point for adding local refinement. Guessing a value can result in a huge number of elements or a very coarse mesh. Reducing the global size is one refinement option, but it is a very expensive solution. The number of elements with the default size is 8,332.

Halving the element size to 0.095 gives 67,844 elements, halving again to 0.0475 gives 474,797 elements. As usual the objective is to put fine mesh control where it matters. Autodesk Nastran has local mesh controls as shown in Fig. 5.

Any number of local controls can be used to target vertex, line or surface geometry. As an exercise, I assumed that a fine mesh is needed around the bolt holes on the horizontal faces to investigate stresses. Fig. 6 shows the result of increasing the mesh refinement locally on the edges of both of these holes.

The element relative local size and element count is:

Figure	Size	Elements
6(a)	1	8,332
6(b)	0.5	10,849
6(c)	0.25	15,954

The final Fig. 6(d) is a result of reducing the Element Growth Rate to 1.2 from a default of 1.6. The effect is to keep a fine mesh bias over a larger distance away from the bolt hole. The number of elements using this method is 33,113.

Analysis Setup

The bracket is assumed to be connected to a stiff backing structure at the outer pair of bolt holes on the YZ plane flange. This represents a case where the inner bolt pair has been missed in assembly. The bolts act as a standoff, rather than clamping the structure to the backing. The constraint setup is shown in Fig. 7.

The constrained degrees of freedom (DOF) can be set manually, or simple constraint options such as symmetry can be invoked. Cylindrical constraints such as bolt hole rotation can be set up, but the required coordinate system must be defined in the Autodesk Inventor Model first and then referenced here.

The task for this overview is to carry out a Normal Modes analysis and a subsequent Modal Transient Dynamic analysis on the bracket. The default analysis is linear static. Right mouse-clicking on the Analysis object in the Analysis tree, and selecting edit allows any analysis to be set up, as shown in Fig. 8.

At the time of this writing, all analysis options are available with a standard license. The Autodesk Nastran standalone solver is also bundled with no restrictions on the input file origin.

Selecting Normal Modes allows control over output. I deselected reaction forces and stress—only the eigenvectors (displacements) have any meaning. An additional control object named Modal Setup 1 is created in the Analysis tree and gives access to further context-based parameters. I kept all defaults, which included the number of modes and extraction method, but opted to save the modal database.

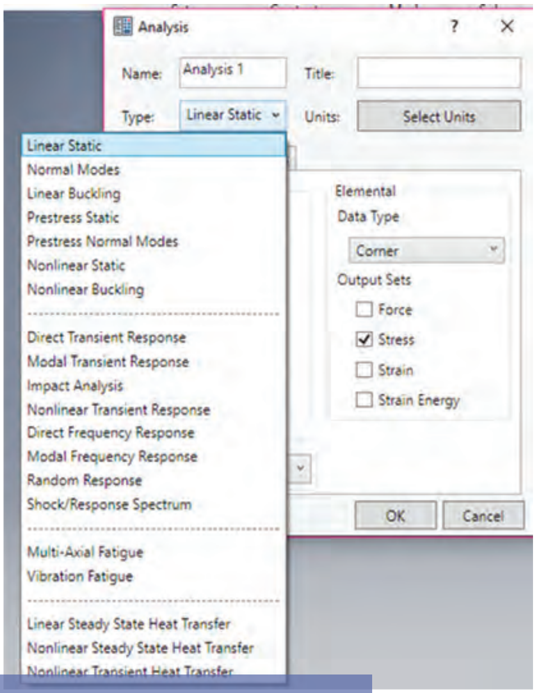


Fig. 8: Analysis type selection.

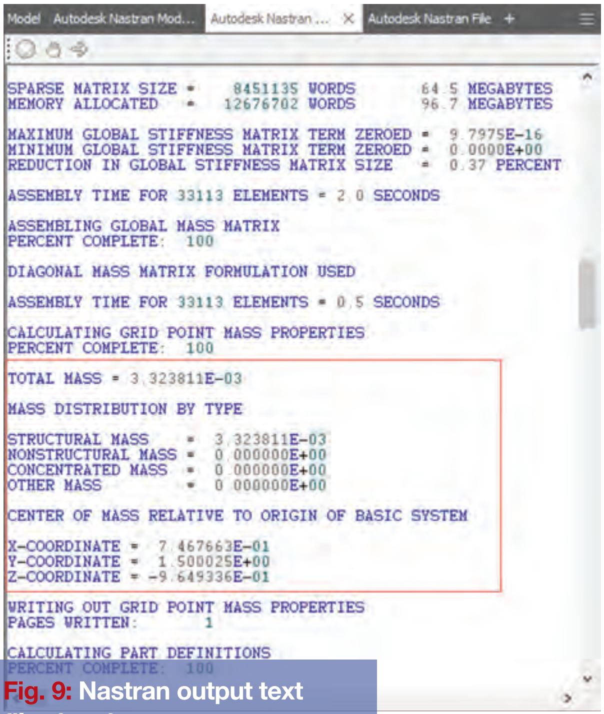


Fig. 9: Nastran output text file showing mass property calculations.

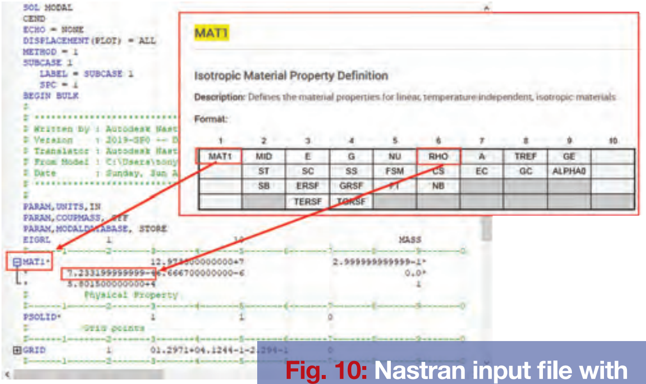


Fig. 10: Nastran input file with MAT1 help overlaid.

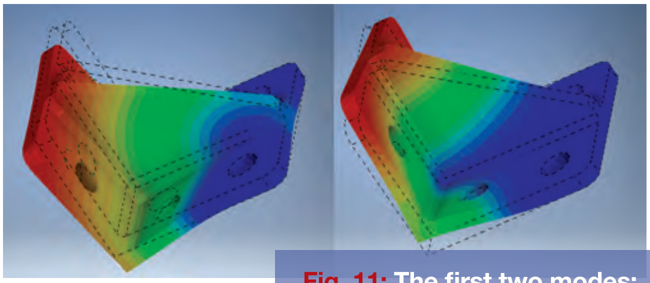


Fig. 11: The first two modes: Mode 1 (left) 1044 Hz, Mode 2 (right) 1221 Hz.

Running the analysis creates two more view panels alongside the Model (Autodesk Inventor) and Autodesk Nastran Model Tree. These are shown in Fig. 9.

The Nastran output file tab has been selected in Fig. 9. I have highlighted the mass property calculations in the Nastran solver. The structural mass is reported as 3.3238e-3 units. This is the correct value in pounds mass (lbm). This is checked by dividing the weight by gravity, 386.4 inches per second squared. The translator between Autodesk Inventor and Autodesk Nastran appears to be hardwired to make this weight-to-mass conversion; it's something to consider.

The output file is useful for debugging and understanding the calculation flow. Experienced analysts will welcome this additional insight, and it is a great tool for newcomers to start to investigate the process more deeply.

In that vein, the other new tab created is the Autodesk Nastran input file, shown in Fig. 10.

The syntax of the input file takes some effort to interpret, but will give a deeper understanding of the analysis. I have overlaid part of the material property (MAT1) description from the documentation. The Nastran documentation can be loaded locally; the default is online. Hitting F1 while highlighting the input file will spawn the documentation. A search will then take users to the relevant data. The NEi Nastran original version was fully context sensitive and the relevant documentation was spawned automatically. I hope Autodesk Nastran's developers can reincorporate this to enhance the learning curve and productivity.

In Fig. 10 I have highlighted the density term RHO. The Nastran input file is definitive and hence it is useful to be able to check the translation within the Model database.

Analysis Results

The first two modes from the analysis results are shown in Fig. 11. The plots show the first bending mode and the first torsional mode. I have modified the default settings to give a banded contour view, switched element edges off and deselected maximum and minimum markers. It is straightforward to move between the frequencies, retaining this view. Animation also has good controls. I increased the number of frames to 24 and used the oscillate option. I found it easier to move between modes with animation by using the control panel available from the Analysis tree view, rather than the ribbon controls.

Running a Normal Modes analysis also spawns a set of XY plots. The first is a Frequency versus Mode Number plot, and the next six are Modal Effective mass plots: one for each DOF.

These plots are important for carrying out a modal survey. In this case, the first two modes are similar at relatively low frequencies, but the frequencies climb rapidly with more complex modes. A typical response spectrum cutoff may be at 2000 Hz, and the first two modes are the only two of concern. Alternatively, if a payload is attached to the bracket, approximate hand calculations can estimate the drop in frequency and whether higher modes may become important. The modal effective mass graph shows mode 1 contributing in a vertical (Z) sense, but mode 2 does not. This allows excellent predictions for base motion excitation and approximate indications for external excitation.

For the next task, I created a transient analysis with a vertical (Z) impulse being applied at the two bolts in the XY plane. The setup is shown in Fig. 12.

I edited the Normal Modes analysis and converted it to a Modal Transient analysis. This spawned new objects in the tree view. There are other possibilities, such as creating a duplicate analysis and then editing. The motivation is to inherit the Normal Modes analysis settings.

I edited the Modal Setup object to reuse the Modal database created in the Normal Modes analysis. For a large model this can be a significant saving in resource and run time. Damping is defined via the Damping object in the tree view. Constant Modal damping is very easy to apply— just defining the value. I used 1% critical damping. Rayleigh, Structural and variable Modal damping are all available.

Using the Loads object in the tree view, loading is applied in the usual way as a static loading, with an option to create the time dependency on the fly via a table. Alternatively, a table can be separately defined, with the ability to paste external data.

Time step size and number of time steps are input via the Dynamics Setup object created in the tree view. If you know the step size and duration, which is the typical case, the number of steps is calculated automatically.

The analysis results are presented as a vertical (Z) deflection time history at the edge node indicated by the red star in Fig. 12. Results are shown in Fig. 13 for two analysis runs.

The first analysis used the standard Nastran file setup from Autodesk In-CAD. The second analysis used a modified Nastran file to look at the contribution from mode 4 only. The file modification was carried out from within the Autodesk Nastran File tab using the direct editing tools available and the local help documentation.

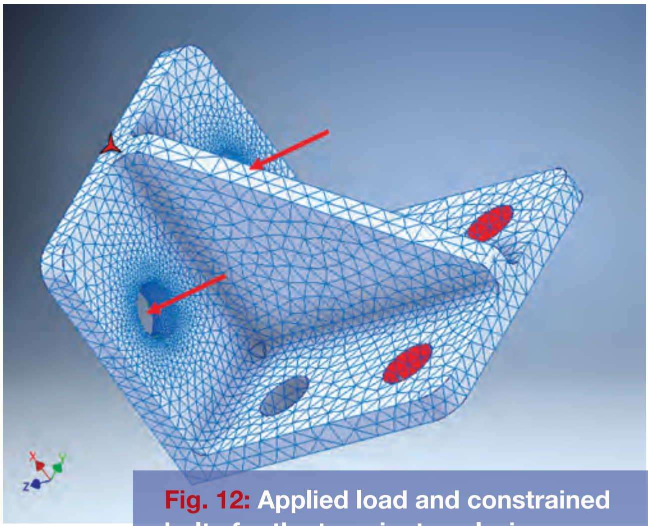


Fig. 12: Applied load and constrained bolts for the transient analysis.

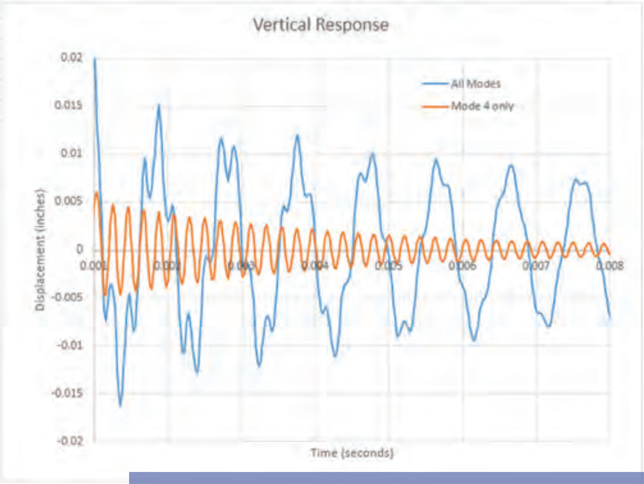


Fig. 13: Transient response at key node using all modes and mode 4 only.

The ability to filter modes to gain understanding in this way is very powerful. The same modal database is reused each time.

FEA-CAD Combo

Autodesk Nastran In-CAD is an interesting combination of a traditional FEA tool embedded in a CAD environment. Much of the product's richness is apparent in the embedded solution. Together with the availability of the full standalone product, this will be attractive to experienced analysts. On the other hand, the user-friendly CAD-like environment is attractive to beginners or infrequent users of FEA. The availability of all analysis types at a single licensing level is good news for all. DE

Tony Abbey *has an Autodesk Nastran Dynamics course in build for LinkedIn Learning, as a follow-up to his SOLIDWORKS Simulation courses. He also will be presenting a Dynamics master class at Autodesk University in November.*

Lenovo ThinkPad P52s: Thin, Lightweight and Affordable

A new P-series mobile workstation for on-the-go professionals.

BY DAVID COHN

The thin, lightweight Lenovo ThinkPad P52s is housed in a dark gray sculpted case and delivers decent performance at an affordable price. *Images courtesy of Lenovo.*

THE LENOVO THINKPAD P SERIES mobile workstations have always been an impressive fusing of portability and power. The ThinkPad P71 we recently reviewed (*DE* May 2018) proved itself the new mobile price/performance leader. This made us understandably enthusiastic when Lenovo offered to send us its newest addition to the P series lineup, the ThinkPad P52s.

The Lenovo ThinkPad P52s is the thinnest and lightest mobile workstation yet from the Chinese manufacturer, offering a choice of 8th generation Intel quad-core CPUs in an Ultrabook format. The system comes housed in a charcoal gray case made of glass-fiber reinforced plastic. Overall, it measures 14.4x10.0x0.8 in. and weighs just 4.39 lbs. The small, 65-watt power supply (4.25x1.75x1.13 in.) adds just 0.61 lbs. more, including its cables.

All configurations of the P52s include an NVIDIA Quadro P500 discrete graphics processing unit (GPU). Prices start at $1,070 for a system equipped with a 1.7GHz Intel Core i7-8350U quad-core processor, a 1920x1080 display, 8GB of RAM, a 500GB 7200rpm SATA drive, Windows 10 Home and a one-year warranty. But, of course, the system we received included several extra-cost options.

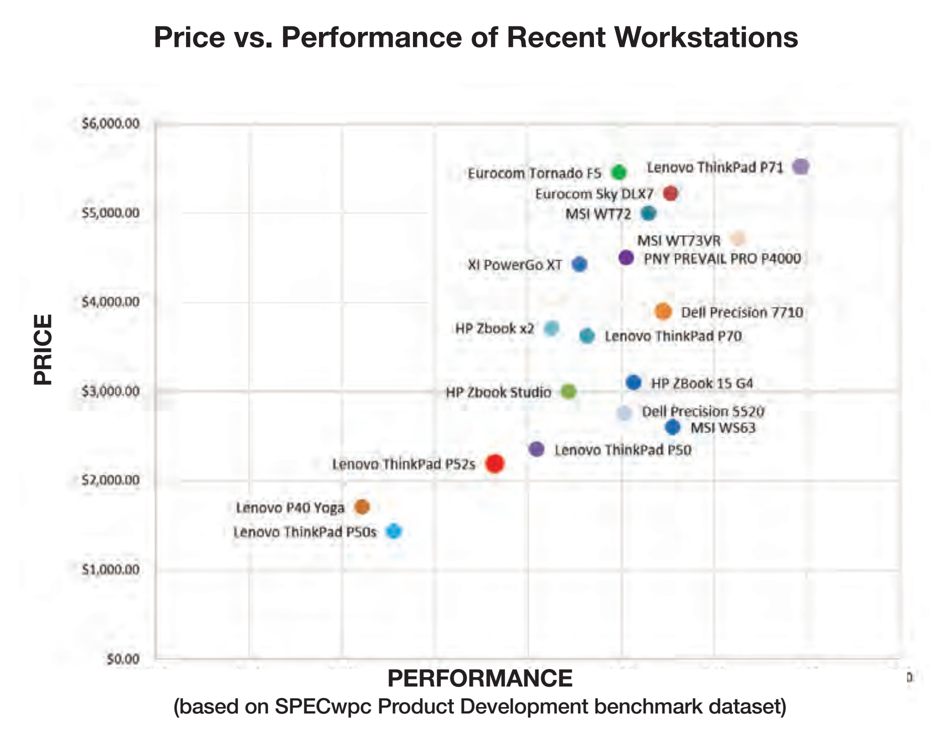
Keyboard and Display

Raising the lid reveals a 15.6-in. display and a spill-resistant keyboard with 105 mostly full-size keys, including a separate numeric keypad. Lenovo keyboards are among the best available in any laptop, and the P52s is no exception. The keyboard in our evaluation unit included backlighting, which is $25 extra. Lenovo also offers a choice of three in-plane switching anti-glare display panels: two full high-definition (1920x1080) 2K displays (with or without touch) and a ultra high-definition (3840x2160) 4K display (without touch). The 1920x1080 panel with multi-touch is just $85 more, while the 4K panel included in our evaluation unit added $191.

A 720p HD webcam flanked by a pair of microphones is centered above the display. A similar camera with infrared ($25) is available on all but the non-touch enabled FHD display and is required if you want to use facial recognition to sign in to your computer.

A round power button is located in the upper-right corner, just above the numeric keypad, and a 3.8x2.75-in.

touchpad with three buttons is centered below the spacebar. There is also a red pointing stick nestled between the G, H and B keys. A spot for an optional fingerprint reader ($11) is just to the right of the touchpad. The caps lock and number lock keys each have their own LEDs as do separate keys dedicated to the speakers, microphone and function lock. The system includes a pair of two-watt speakers.



Price/Performance chart based on SPECwpc Product Development benchmark dataset.

Modest Options

In addition to the CPU included in the base configuration, Lenovo also offers the P52s with a 1.8GHz Intel Core i7-8550U or the 1.9GHz Intel Core i7-8650U included in our evaluation unit (adding $170). Intel's Kaby Lake processor, which also includes integrated Intel UHD Graphics 620, has an 8MB SmartCache, a 15-watt thermal design power rating and a maximum turbo frequency of 4.2GHz.

Although the base system includes just 8GB of memory, the ThinkPad P52s can accommodate up to 32GB of RAM. Our system came with 16GB installed using a pair of 2400MHz memory modules, increasing the price by $106. A single 16GB dual-inline memory module is the same price, however; something to consider if you anticipate adding more memory in the future.

Lenovo offers a choice of storage devices, including hard drives of up to 1TB and solid-state drives ranging from 256GB to 1TB. Our evaluation came with a 1TB Samsung PCIe NVMe M.2 drive, which added $626. Although the system only accommodates a single drive, Lenovo does offer an optional 16GB solid-state Intel Optane PCIe drive on systems equipped with SATA hard drives.

The ThinkPad P52s is a bit more limited in terms of connectivity than other Lenovo mobile workstations we have reviewed. The right side provides a combination headphone/microphone combo jack, a four-in-one media-card slot (MMC, SD, SDHC, SDXC), a pair of USB 3.1 ports including one that is always on when the system is connected to AC power, an HDMI port, an RJ-45 ethernet jack and a lock slot.

The left side houses a pair of USB Type-C connectors, one of which is also Thunderbolt 3 compatible. These ports can transfer data, charge the computer or connect the computer to an external display. There is also a docking station connector (a ThinkPad Thunderbolt dock currently sells for $196) and room for an optional Smart-Card reader (a $10 option). Intel dual-band wireless-AC 8265 plus Bluetooth 4.1 comes standard.

The P52s offers a somewhat unique battery arrangement. A four-cell Li-Ion 32Whr front battery is housed inside the system. You then have a choice of removable rear batteries that can be swapped out while the system is running. In addition to the standard three-cell 24Whr rear battery provided with our evaluation unit, Lenovo also offers a six-cell 48Whr battery for $14 more or a six-cell 72Whr cylindrical battery for $29. The pair of standard batteries kept our system running for 5.5 hours. The system remained cool and nearly silent throughout our tests, even when under heavy compute loads.

Lackluster Performance

Although we have come to expect Lenovo workstations to deliver top-of-class performance, we weren't expecting that same level of performance from this thin, lightweight system.

As expected, on the SPECviewperf benchmark, which focuses on graphics, the Lenovo ThinkPad P52s was the slowest mobile workstation we have tested in the past

Mobile Workstations Compared	**Lenovo ThinkPad P52s** 15.6-inch 1.9GHz Intel Core i7-8650U quad-core CPU, NVIDIA Quadro P500, 16GB RAM, 1TB NVMe PCIe SSD	**HP Zbook x2** 14.0-inch detachable 1.9GHz Intel Core i7-8650U quad-core CPU, NVIDIA Quadro M620, 32GB RAM, 512GB NVMe PCIe SSD	**Lenovo ThinkPad P71** 17.3-inch 3.1GHz Intel Xeon E3-1535M v6 quad-core CPU, NVIDIA Quadro P5000, 64GB RAM, two 512GB NVMe PCIe SSDs in RAID 0 array	**HP Zbook 15 G4** 15.6-inch 3.0GHz Intel Xeon E3-1505M v6 quad-core CPU, NVIDIA Quadro M2200, 32GB RAM, 512GB NVMe PCIe SSD	**PNY PREVAIL PRO P4000** 15.6-inch 2.8GHz Intel Core i7-7700HQ quad-core CPU, NVIDIA Quadro P4000, 32GB RAM, 512GB NVMe PCIe SSD and 2TB 5400rpm SATA HD	**Dell Precision 5520** 15.6-inch 3.0GHz Intel Xeon E3-1505M quad-core CPU, NVIDIA Quadro M1200M, 32GB RAM, and 512GB NVMe PCIe SSD
Price as tested	$2,196	$3,710	$5,517	$3,095	$4,499	$2,759
Date tested	6/12/18	4/5/18	12/14/17	12/1/17	11/28/17	11/27/17
Operating System	Windows 10	Windows 10	Windows 10	Windows 10	Windows 10	Windows 10
SPECviewperf 12 (higher is better)						
catia-04	28.64	30.81	145.81	71.62	110.72	44.56
creo-01	33.26	34.75	119.20	69.15	94.21	45.88
energy-01	0.55	0.63	14.51	5.29	12.40	3.66
maya-04	20.96	23.25	92.67	50.99	73.75	34.47
medical-01	9.41	11.02	66.51	25.62	50.11	16.48
showcase-01	12.55	15.94	65.73	32.19	60.28	23.29
snx-02	43.91	26.33	250.00	58.62	111.05	34.93
sw-03	50.01	57.28	151.51	97.14	121.45	72.15
SPECapc SOLIDWORKS 2015 (higher is better)						
Graphics Composite	1.94	2.36	3.64	6.60	3.44	3.44
Shaded Graphics Sub-Composite	1.17	1.44	2.11	3.33	2.00	2.25
Shaded w/Edges Graphics Sub-Composite	1.64	2.22	2.79	4.65	2.66	3.27
Shaded using RealView Sub-Composite	1.48	1.72	2.54	4.73	2.42	2.70
Shaded w/Edges using RealView Sub-Composite	1.98	3.05	3.22	7.85	2.98	4.51
Shaded using RealView and Shadows Sub-Composite	1.69	1.54	2.93	5.40	2.79	2.31
Shaded with Edges using RealView and Shadows Graphics Sub-Composite	2.00	2.57	3.45	8.34	3.17	3.69
Shaded using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	3.01	3.17	9.61	15.31	9.00	4.55
Shaded with Edges using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	3.54	4.77	9.66	21.43	9.12	6.69
Wireframe Graphics Sub-Composite	2.43	2.65	3.13	3.41	3.11	2.96
CPU Composite	1.72	1.75	2.39	4.07	2.21	2.22
SPECwpc v2.0 (higher is better)						
Media and Entertainment	1.71	1.97	3.38	2.63	2.53	2.51
Product Development	1.82	2.13	3.47	2.57	2.53	2.52
Life Sciences	1.83	2.25	4.18	3.01	3.03	2.86
Financial Services	1.91	0.85	3.14	2.87	2.47	2.88
Energy	1.42	0.87	6.43	2.11	2.67	2.58
General Operations	1.20	1.68	1.90	1.62	1.11	1.64
Time						
Autodesk Render Test (in seconds, (lower is better)	89.70	78.00	48.40	72.70	58.90	87.10
Battery Life (in hours:minutes, higher is better)	5:33	5:00	6:05	13:30	4:00	9:24

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

three years. Only the older ThinkPad P50s and P40 Yoga have yielded slower graphic performance. The results on the SPECapc SOLIDWORKS benchmark were similarly lackluster.

The P52s also ranked near the bottom of the field on the very demanding SPECwpc benchmark, although it did outperform the HP ZBook x2 on some of the tests. Its average time of 89.7 seconds to complete our AutoCAD rendering test was also among the slowest recorded for a mobile workstation over the past three years. But that result was nearly twice as fast as the ThinkPad P50s (*DE*, March 2017).

Although the base configuration comes with Windows 10 Home, our system included Windows 10 Pro, a $30 upgrade. The standard warranty covers the system for just one year with depot or carry-in service. Additional coverage is available at the time of purchase that can extend the warranty for up to five years, including accidental damage protection. Our system came with a three-year warranty.

The Lenovo ThinkPad P52s is certified for more than 100 applications from independent software vendors including Autodesk, Dassault Systèmes, PTC and Siemens PLM Software. The P52s has also passed 11 MIL-STD 810G military certification tests that demonstrate the durability of the system and meet requirements for government and military customers.

As configured, the ThinkPad P52s we received priced out at $2,196 after an automatic 10% online discount, making this new ThinkPad one of the most affordable mobile workstations on the market today. Although it won't replace a desktop system, it will certainly enable the ability to get work done while on the go. **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 www.dscohn.com.*

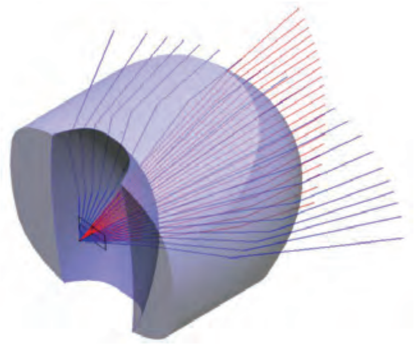
INFO ➔ Lenovo: Lenovo.com/thinkstation

Lenovo ThinkPad P52s

- **Price:** $2,196 as tested ($1,070 base price)
- **Size:** 14.4x10.0x0.8 in. (WxHxD) notebook
- **Weight:** 4.39 lbs. (plus 0.61-lb. external power supply)
- **CPU:** Intel Core i7-8650U 1.9GHz quad-core w/ 8MB cache
- **Memory:** 16GB DDR4 (2x8GB) at 2400MHz
- **Graphics:** NVIDIA Quadro P500 (2GB GDDR5 memory, 256 CUDA cores)
- **LCD:** 15.6-in. 4K (3840x2160) IPS
- **Hard Disk:** Samsung 1TB PCIe NVMe M.2
- **Floppy:** None
- **Optical:** None
- **Audio:** Built-in speakers, headphone/microphone jack, built-in microphone array
- **Network:** Integrated Intel Dual Band Wireless-AC 8265 plus Bluetooth 4.1, one RJ45 gigabit Ethernet port
- **Other:** Two USB 3.1 (one always on), one USB Type-C, One USB 3.1 Type-C/Thunderbolt 3, HDMI, 4-in-1 media card slot, 720p webcam, dock connector
- **Keyboard:** Integrated 105-key full-size backlit keyboard with numeric keypad
- **Pointing device:** Integrated touchpad and pointing stick with three buttons

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.*



Design and Analyze Illumination Optical Systems

LightTools' Tolerance Manager helps predict illumination system manufacturability.

LightTools is a 3D optical engineering and design system. It supports virtual prototyping, simulation, optimization and photorealistic rendering. Users build their solutions around a core module with 3D solid modeling functionality for creating and visualizing optical and opto-mechanical systems.

The optional modules include illumination simulations, optimizations, advanced physics, bidirectional CAD translators and so on. LightTools is professional-level.

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Autodesk Netfabb 2019 Released

Simulation and latticing features updated; multiple productivity enhancements.

Netfabb is a comprehensive suite of professional-level additive manufacturing design, simulation and optimization tools. Netfabb starts with a Standard edition, with import and prepping tools. The Premium edition has advanced build supports, complex lattice structures and functionality for preparing parts for post-processing. Premium subscribers have access to pay-per-use Netfabb Simulation for cloud-based, metal powder bed process simulations.

A complimentary trial is available.

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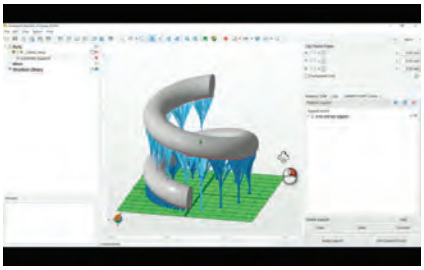

Instant Quoting Engine Upgraded

On-demand platform releases new version of its instant quoting engine.

Xometry recently deployed version 3.0 of its Instant Quoting Engine. It starts with three basic selections: materials, fabrication process and constraints. Material options are metal, plastic or both. Fabrication processes include computer numerical control machines, sheet metal, urethane casting and 3D printing. The Instant Quoting Engine provides instant manufacturability feedback; and details lead times and costs. Also, a 3D viewer displays design feedback on the model.

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Solid Edge 2019 Released

Portfolio expansion includes new capabilities for electrical design and more.

Solid Edge from Siemens PLM Software is a software portfolio for product development from art to part. At its heart is Solid Edge Mechanical with ST for the 3D model creation business. From there, any size outfit can expand their Solid Edge environment into their arena—sheet metal and electrical design, manufacturing, whatever.

Solid Edge supports development with things like simulation, built-in rendering, technical documentation and data management functionalities, etc.

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Next-Gen Engineers

Student Design Competition Profile: The RIT Baja SAE

Extraordinary Vehicle Design

BY JIM ROMEO

VEHICLE DESIGN ASSUMES a different dimension when students design vehicles that aren't so ordinary. That's the case with the SAE International Collegiate Design Series that focuses on Baja vehicles. At Rochester Institute of Technology (RIT), students participate in the competition, which is led by Martin Gordon, a professor of manufacturing and mechanical engineering technology in the College of Engineering Technology at RIT and also the faculty advisor to RIT Baja SAE. We spoke to Gordon to learn more about the competition.

Digital Engineering: Can you provide an overview of the RIT Baja SAE?

Martin Gordon: The Baja Student Design Competition, established in 1976, is sponsored by SAE and is an international series of events where student engineers design and build off-road vehicles.

RIT has competed for more than 25 years, winning national and international competitions. The university also hosts an international event every three years and will do so again in June 2019. At the previous event in 2016, more than 1,200 students participated. More than 100 teams from across the U.S., Canada, Brazil, India, Mexico, Venezuela and South Korea participate.

Students on the teams are predominantly from engineering and engineering technology programs, but [there are also] students from business, computing and imaging science programs to emulate the project teams found in businesses today. Teams must provide information during competitions about how Baja SAE vehicles are designed, built and tested as well as compete in field events such as rock and hill climbs, acceleration and maneuverability challenges and a four-hour endurance race.

DE: Can you tell us about some of the designs that are part of the event and how they came to be?

Gordon: The events produce amazing off-road vehicles, strong engineers who can successfully work on teams and employment opportunities—for both companies and students.

All the vehicles start with a single-cylinder commercial engine—similar to one used for go-carts and smaller motorcycles. There are set design requirements for size and weight. From there, teams develop off-road vehicle designs that are unique in style. RIT is one of the few universities that build many of the parts and equipment in house because they have available top-notch fabrication facilities and wonderful support from the university—all the way up through the president's office.

A competitor in the Baja Student Design Competition gets some air. *Image courtesy of RIT.*

Individuals from companies such as GM, Cummins, Caterpillar, General Electric, Honda, Toyota, SpaceX and Polaris not only volunteer as design, safety and event judges, they also recruit prospective employees from the different teams competing. They are able to see firsthand how students interact with each other and with other teams as well as how they contribute to the design process. **DE**

Jim Romeo *is a freelance writer focused on business and technology topics. Contact him vis JimRomeo.net.*

ADVERTISER INDEX

| **COMMENTARY** |

by Randall Newton

The New Decentralized Innovation Stack

A TECHNOLOGY STACK is a set of IT products or services that independently are useful and important, but when integrated become a platform for greater innovation. The term has its origins in software development, where a "stack" of aligned resources (operating system, database, programming language, etc.) is required to write applications.

Technology stacks are identified, not invented. For example, the tech stack that launched the internet revolution was called LAMP, named for the four most important software tools for creating web infrastructure: Linux, Apache, MySQL and PHP. The acronym was originally coined by Michael Kunze, while writing in the German magazine *c't* in 1998. Today's web is still largely based on the original LAMP tech stack.

The current reigning tech stack is CAMS—cloud, analytics, mobile and social (also known as SMAC). Cloud makes data more widely available, analytics make data more valuable, mobile makes data more consumable and social makes data more actionable.

The LAMP stack drove three generations of web development and continues to be an innovation engine. The most important product to come from the CAMS stack is arguably the smartphone, which in turn became a platform for various new products and services. Other examples of CAMS-based innovation include industrial robots, construction drones and the internet of things (IoT).

From LAMP to CAMS to ROADI

A new technology stack is evolving as the next engine of innovation: ROADI (real-time operational autonomous distributed intelligence). ROADI will turn products and services into autonomous discreet agents.

The clearest example of the ROADI stack is from the automotive industry. Self-driving cars must possess intelligent and autonomous behavior, and always respond in real time to the environment. Their actions are based on a refined notion of trusted behavior. The necessary computation and connectivity cannot be centralized in a server or even a cloud; it must take place in each vehicle and in every other object on or near the road.

Assembling the ROADI Stack

There are several innovations behind the emerging ROADI stack. Graphics processing units (GPUs) have far exceeded their original purpose and are now more responsible for computational innovation than CPUs. Also known as GP-GPUs (general purpose GPUs), they give autonomous cars their vision and their "knowledge" of the world, processing millions of bits of information every second to provide real-world interactive capabilities.

The IoT and the industrial IoT (IIoT) are abstractions that describe various interconnected technologies, including distributed computation applications known as edge computing, fog computing, the more established cloud computing and such emerging technologies as microscopic CPUs. As the tools mature, IoT/IIoT devices will exhibit autonomous, decentralized behavior—interacting with each other without the need for centralized control.

Deep learning has changed how we use big data. It allows the emergence of behavior we describe as intelligent, providing millions of autonomous devices with the logic to operate in real time.

Blockchain technology will provide new elements crucial to autonomous distributed intelligence as the disintermediation of trust and an open transaction ledger. Blockchain uses a cryptographic ledger to bring immutable proof and automated smart contracts into the stack. For example: If a self-driving car is in an accident, a blockchain-based smart contract could be automatically triggered, relationally binding it to any other smart objects involved in the accident and the physical jurisdiction. A record of the car's recent behavior will become part of the public record on the blockchain ledger, making it easier to assign responsibility for the accident.

Immersive and interactive display technologies such as augmented reality, machine vision and heads-up displays will provide a conduit for human interaction with ROADI technologies.

Ethical Considerations

Every major technical innovation requires society to respond to new ideas. Eleven years after the launch of the iPhone, we are still trying to understand how smartphones influence behavior. When smart, connected products become ROADI products, there are new considerations. Can robots witness a crime? Can a smart factory order supplies without human intervention? Will immutable records stand up in court? At its best, engineering takes legal, ethical and moral parameters into consideration. How industry responds to these social meta-specifications will likely prove to be the biggest hurdle or the biggest asset in the development of ROADI products and services. **DE**

Randall S. Newton *is managing director of Consilia Vektor (consiliavektor.com), a technology analysis and marketing advisory service specializing in product development, construction technology, and distributed ledger (cryptocurrency) applications.*