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## Digital Engineering

May 2019

- Digital Twins & SMBs
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FOCUS ON: Autonomous Technology


# AUTOMATION
## Land, Air & Sea

FRACTURE MECHANICS ANALYSES

MSI MOBILE WORKSTATION REVIEW

by Jamie J. Gooch

# The Cart Before the Autonomous Car

AT THE ADDITIVE MANUFACTURING Users Group (AMUG) conference in Chicago last month, a lunchtime conversation summed up the state of additive manufacturing/3D printing technology, and many other technologies.

A large supplier to the aerospace industry was voicing a minor complaint about his company's 3D printers to a representative from a competing 3D printer company. That representative, as you might expect, said his company's 3D printers did not suffer from that particular malady.

"Where were you five years ago when we did all this?" asked the aerospace supplier.

"We weren't a company yet," replied the 3D printer manufacturer.

It was a small example of concerns I've heard again and again from many sectors *Digital Engineering* covers: The state of the art is changing so quickly, it's tough to keep up. In additive manufacturing (AM), new processes may require new materials, new design techniques with new CAD and simulation software to support them, new testing and quality control measures, and on and on. (You can read more about how the AM industry is meeting those challenges on page 11.) Adopting a new technology causes a ripple effect that can disrupt tried-and-true workflows and even entire industries.

The 3D printing sector isn't alone in this, of course. Last fall when we asked our audience what challenges or issues they face when developing a digital thread, "keeping up with new technologies" was second only to "complexity of design and development."

## Autonomy, Hold the Baloney

Perhaps no recent technological upheaval embodies disruption more than autonomous vehicles. Self-driving cars that can get us safely from point A to point B would have ripple effects felt beyond the auto industry. How would they change healthcare and insurance? What about city planning and infrastructure? What jobs would they create or eliminate? What entertainment options would people purchase as they ride along? Established businesses and start-ups are scrambling to correctly envision (and invest in) the future.

But there's a lot of engineering to get those self-driving cars, or aircraft or watercraft from point A to point B, as we describe in this issue's focus, starting on page 12. That engineering will take time, as will the regulations and cultural shifts that would accompany such a disruption.

Hype is part of the innovation process. It gets researchers, regulators, investors, corporations and the general public all moving in the same direction to advance a particular set of technologies. Even if full autonomy isn't achieved by a certain date, the road to that goal is filled with important milestones that advance the various technologies involved.

## Too Fast, Too Furious?

The danger to design engineers in the rush to meet hyped up expectations is two-fold. Most importantly, product designers and engineers may be pressured to cut corners, which could have life-and-death consequences. Design engineers have a responsibility to be the voice of reason, balancing the desire to meet short deadlines and incredibly complex product development with the need for rigorous simulation, testing and quality control.

Engineers aren't immune to hype. At AMUG, I heard a number of anecdotes from different rapid prototyping and manufacturing service providers who were still fielding requests for additive manufacturing, rather than requests for the most efficient, cost-effective way to produce a part.

The other, less dire, danger is that companies will wait until things slow down before investing in new technologies that could actually help them meet the oft-opposed goals of better, faster, cheaper. Technologies such as AM, computer-aided optimization, artificial intelligence, augmented reality and more are all moving so fast, it's difficult to discern the leading edge from the bleeding edge. Here again, engineers must be involved in determining when and where to invest the company's resources.

Approach new technology adoption with the same rigor as you would product design, validation and testing. There will always be something better coming along, but the current iteration of technology may be just what you need now. DE

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DE
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TECHNOLOGY FOR OPTIMAL ENGINEERING DESIGN

# INSIDE

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## FOCUS ON AUTONOMOUS TECHNOLOGY



## FEATURES

### DIGITAL THREAD





**ON THE COVER**:
Volocopter, Waymo, Ken Kostel © Woods Hole Oceanographic Institution, Getty Images/Calmara.



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# Vendors Advance Autonomous Vehicles

## Top 10 Vendors

1. Waymo (formerly the Google Self-Driving Car Project)
2. GM/Cruise
3. Ford Autonomous Vehicles
4. Aptiv (formerly known as Delphi Automotive)
5. Intel-Mobileye
6. Volkswagen Group
7. Daimler-Bosch
8. Baidu
9. Toyota
10. Renault-Nissan-Mitsubishi Alliance

## 10 Ranking Criteria

1. Vision
2. Go-to-market strategy
3. Partners
4. Production strategy
5. Technology
6. Sales, marketing and distribution
7. Production capability
8. Product quality and reliability
9. Product portfolio
10. Staying Power

*— "Navigant Research Leaderboard: Automated Driving Vehicles," Navigant Research, March 19, 2019*

## $300 Million

GM plans to invest $300 million in its Orion Township plant in suburban Detroit where it builds electric vehicles (EV) and self-driving vehicles. Its next-generation of EV and self-driving vehicles are slated to begin production in 2023.

*— General Motors, March 22, 2019*

## $15.8 Billion

Audi Group (part of the Volkswagen Group), says it will invest €4 billion in electric, digitization and autonomous driving efforts through 2023.

*— Audi, Dec. 4, 2018*

## $900 Million

Ford is investing $900 million through 2023 mainly via expanded production at its Flat Rock, MI, assembly plant—including fully electric vehicles—but also via an autonomous vehicle center where it says it will make autonomous vehicles starting in 2021, focusing on commercial services.

*— Ford Motor Co., March 20, 2019*

## $13.6 Million

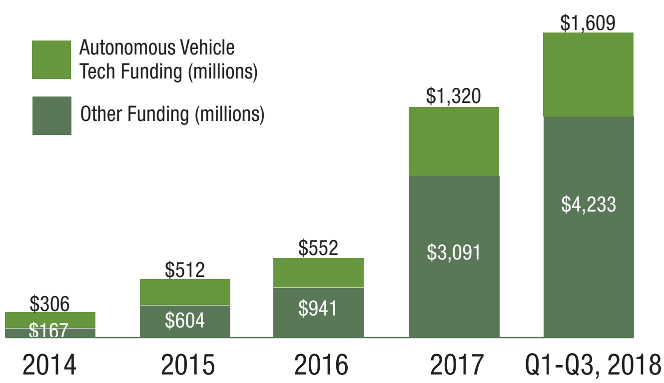
Amount Waymo plans to spend on a new facility in Michigan to retrofit cars with autonomous technology.

*— Michigan Economic Development Corporation, Jan. 22, 2019*

## $4.2 Billion

Since 2014, funding to companies working on semi-autonomous and autonomous driving has eclipsed all other segments of auto tech. The $4.2 billion does not include what automakers are investing in developing their own new technologies.

*— "Autonomy Is Driving A Surge of Auto Tech Investment," CB Insights, Sept. 27, 2018*



# Slow the Self-Driving Roll?

**46%** are very unlikely, 15% are somewhat unlikely, 9% are somewhat likely, 12% are very likely to ride in a self-driving car.

*— "Brookings survey finds only 21 percent willing to ride in a self-driving car," Brookings Institution, July 2018.*

**56%** are very concerned about the security of the data collected by the driverless vehicles.

*— Public Policy Polling survey commissioned by Consumer Watchdog, May 16, 2018.*

**57%** of respondents say they are likely or very likely to support autonomous vehicles' potential to transform the lives of Americans who are elderly or disabled.

*— Morning Consult survey commissioned by Coalition for Future Mobility, August 2018.*

**16%-28%** Men (28%) are more likely than women (17%) to say they'd ride in a self-driving car. Young people (18 to 34) are more likely to say they'd ride in a self-driving car (27%) than those 55 or over (16%).

*— "Brookings survey finds only 21 percent willing to ride in a self-driving car," Brookings Institution, July 2018.*

**74%** are unlikely to ride in a driverless vehicle if one was made available to them.

*— Public Policy Polling survey commissioned by Consumer Watchdog, May 16, 2018.*

**51%** After being told 90% of accidents involve human error, 27% of respondents said self-driving cars would be helpful in reducing accidents, but 51% did not.

*— "Brookings survey finds only 21 percent willing to ride in a self-driving car," Brookings Institution, July 2018.*

# Delivering the Goods

**55%** of small businesses think their fleets will be fully autonomous in the next 20 years with 38% responding it may happen in as little as 10 years.

*— Survey of small businesses commissioned by the Renault-Nissan-Mitsubishi Light Commercial Vehicle business, Feb. 26, 2019*

**5 seconds** The time the Tesla Semi takes to go from 0 to 60. They can also travel in a convoy, where one or several trucks will be able to autonomously follow a lead Semi.

*— Tesla, November 2017*

By Tom Kevan

# Creating an Origami Sensor Array

TECHNOLOGICAL ADVANCEMENTS OFTEN emerge at the confluence of market trends. This appears to be the case with the ultra-sensitive, multifunction sensor array (go.nature.com/2JMavHg), developed by the Technion-Israel Institute of Technology.

The rise of the Internet of Things, the growing role of printed electronics and the increasing number of technologies that mimic nature have all shaped the system's development. One other factor, however, is in play: The need for greater sensing efficiency and performance.

As a result, the new e-nose/e-tongue sensing system aims to provide engineers with the means to cost-effectively, accurately and simultaneously identify and distinguish trace amounts of different physical and chemical stimuli.

The researchers see the system enhancing various application areas, enabling the monitoring of phenomena ranging from temperature and humidity to light and volatile organic particles.

## Overcoming Existing Shortcomings

A key failing of traditional e-nose/e-tongue sensor arrays is that the sensors reside on a planar substrate, preventing some arrays from differentiating complex physical and chemical stimuli due to sensor crosstalk. Measures to counter this shortcoming often increase the complexity of the designs, which in turn raises cost.

Engineers have sought ways to circumvent these problems, but largely, the measures have proven unsatisfactory. For instance, designers have tried to enable traditional e-nose/e-tongue sensor arrays to perform pattern discrimination between chemical stimuli by linking the systems to time–space-resolved separation techniques, such as gas chromatography (GC).

This approach is unsuitable for distinguishing physical stimuli, such as temperature, and it lacks the agility to handle the timescale of some chemical processes, such as compound separation. GC often requires highly trained professionals, costly maintenance and sophisticated, expensive equipment.

## New Materials

To take these sensor arrays to the next level, the Israeli researchers started developing a tunable conductive ink. The scientists synthesized the ink using a simple one-pot hydrothermal reduction of graphene oxide and dopamine. Dopamine is a catechol-derived molecule that mimics mussel-adhesive proteins.

Testing showed the ink to be compatible with a wide variety of common substrates—including aluminum foil, inkjet paper, nitrile rubber glass and commercially polyimide film—as well as biological materials such as skin and fingernails. The ink is also waterproof, which may enable use in applications demanding the monitoring of physiological variables.

The ink offers other advantages. It is affordable, works with mass production processes, disperses in environmentally-friendly organic solvents, possesses good adaptation and tailoring abilities, and interacts with substrates in a binder-free manner. Equally important, designers can tune the ink's sensory responses for different stimuli by using different substrates.

## Origami Electronics

The most intriguing aspect about the e-nose/e-tongue sensing system is its origami architecture. The concept enables the integration of a group of conductive ink-based sensors onto a paper substrate folded into a hierarchical configuration.

To create the array, researchers deposited conductive ink on alternating layers of the origami structure, creating the internal response indicators linked with wires. Folded in a zigzag pattern, the layers are sealed with tape to form a one- or two-sided array.

The two-sided array has two unsealed entrances, which directly expose the sensing area to stimuli. The one-sided array, on the other hand, has only one entrance. Because of the nature of the paper substrate, the researchers assumed that the layered configuration would be an effective blocking framework for permeable/diffusible stimuli.

Many stimuli simultaneously change, making discrimination between physical and chemical stimuli in complex environments difficult to accomplish with a sensor array based solely on chemical interactions. The researchers at the Technion-Israel Institute of Technology aim to overcome this hurdle with a pre-calibrated array of chemical and physical sensors made from a unique combination of materials.

The scientists suggest their design can expand to possess more characteristics. This might be achieved by adjusting the configuration of the origami or using other functional inks. DE

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SIMULATION 101

By Donald Maloy

# **Simulation Transition:** Meshing Nuts and Bolts

ONE OF THE MOST ENJOYABLE experiences in the process of building a race car is the first visit to the dyno. Tire pressures, high octane fuel and coolant are all carefully assessed prior to that first pull.

As the car's baseline run displays power curve and peak horsepower, you'll jump right to adjusting the air fuel ratio and ignition timing to squeeze as much power out of the engine as possible. This month we discuss this same process as it applies to finite element analysis (FEA).

It's essential to understand the fundamentals of how to adjust a mesh to obtain accurate and reliable results. The FEA dyno session can be broken down into three distinct areas: mesh refinement, element quality and convergence of a result.

### Mesh Refinement

To reduce computational resources and save time, you will probably consider starting your project with a coarse mesh. In doing this, mesh refinement is necessary in some areas to ensure that you have the fidelity required to obtain accurate results. Common considerations should be paid to areas with holes and to elements per shell thickness. Too few elements per hole, and the mesh is likely to provide false information for the stress, strain and displacement.

Refining the mesh with too many elements will work, but this may eat up time. This process is a careful balance between efficiency and accuracy, which comes from experience. Each vendor will generally have guidelines on what they recommend, based on their software.

### Convergence Check

As you travel the path of tweaking and refining the mesh, you may notice that the stress values change. This process of evaluating whether stress values change is commonly referred to as a convergence check. The significance of this test is to understand if the stress values are accurately represented in your analysis.

We wouldn't want to mistakenly interpret results from an inaccurate dataset. If your simulation software has P-adaptive meshing capabilities, you'll notice that with several loops of refinement, the stress values will continue to climb or stabilize as the element size decreases.

Diverging stress values are often referred to as a stress singularity. Removing aspects of the CAD model through defeaturing can sometimes address these matters, as sharp re-entrant corners have infinite stress values. The types of goals you set for the analysis will ultimately drive the decision of refining your geometry to remove the singularity. In some cases, it may not be required.

### Quality Checks

During the initial meshing of your part, you may have noticed that each element appears to be roughly the same size. But there are always a few stragglers that have some disproportionate edges.

When you generate a mesh, the software attempts to fill the entire volume of your part with elements under the parameters you have established. Often with organic shapes or quick transitions from thick to thin areas within the CAD model, the elements become slightly distorted. There are quality checks in place that can be plotted within the simulation software to assist you in uncovering this potential discrepancy.

Plotting the aspect ratio after the CAD model has meshed will show you the areas of high and low aspects. Elements with the ideal aspect ratio would be 1; however, this is not common. The higher the value, generally the less accurate the calculation.

Localized mesh refinement helps lower the aspect ratios. High aspect ratios are most concerning in areas of high stress, as they could very likely be throwing off the results.

Jacobian is another useful quality check that can only be used with elements that have nodes at midpoints within edges, or second-order elements. These types of elements can adapt to curved geometry better than linear elements and are often the choice elements. A Jacobian check ensures that the meshed elements have not developed concave distortion, which can lead to solution errors. If you receive negative values during this check type, mesh refinement and/or defeaturing will need to occur to resolve this problem. DE

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# NVIDIA GTC 2019: Data Science and a $6.9 Billion Bet

**BY KENNETH WONG**

Around noon on Monday, March 18, NVIDIA GPU Technology Conference (GTC) attendees began boarding the long black buses that would shuttle them to the site of the keynote. The 15-minute ride from the convention center took them to San Jose State University's sunny campus.

"Hey, thanks for coming out this way! We got so packed in the old place we had to get you out here. I appreciate you making the trip," said NVIDIA's co-founder and CEO Jensen Huang as he kicked off the event, with 9,000 registered attendees.

In the last decade, NVIDIA has also outgrown its roots in the graphics accelerator business. This year, there were sufficient demos and talks of raytracing, but the biggest announcements have had more to do with autonomous cars, machine learning and data centers.

Part of the keynote was devoted to BMW's use of the Unity game engine and NVIDIA RTX for real-time ray-traced automotive interior simulation and the eye-popping graphics in the Dragon Hound game preview. These satisfied the graphics fans' visual hunger, but NVIDIA is now playing a much larger game. The new tagline of GTC, "The premiere AI conference," clearly spells out what the GPU dragon is chasing.

## The $6.9 Billion Bet

"In the future, the way you design the network is going to change," Huang said. "Instead of a whole bunch of compute nodes connected by networking, the networking and computing will become one continuous fabric."

What followed was the announcement that NVIDIA was buying Mellanox, an interconnect solution provider, for $6.9 billion. Mellanox has been a long-time partner of NVIDIA. With this acquisition, NVIDIA gains the ability to engineer advantageous interconnects directly into its GPU-accelerated supercomputers and high-performance computing (HPC) clusters.

Huang believes data scientists are about to become an integral part of engineering, product development and product lifecycle management. He also believes they need a tool that lets them work independently, without relying on the HPC queue for important workloads.

"The pipeline starts with data science. There's the stage of data ingestion, called data analytics ... The gigantic table of data could be anywhere from gigabytes to terabytes. As a spreadsheet, it wouldn't even load on a normal computer," noted Huang.

With that, Huang unveiled the NVIDIA Data Science Workstation, powered by Quadro RTX GPUs and CUDA-X AI, a collection of software acceleration libraries.

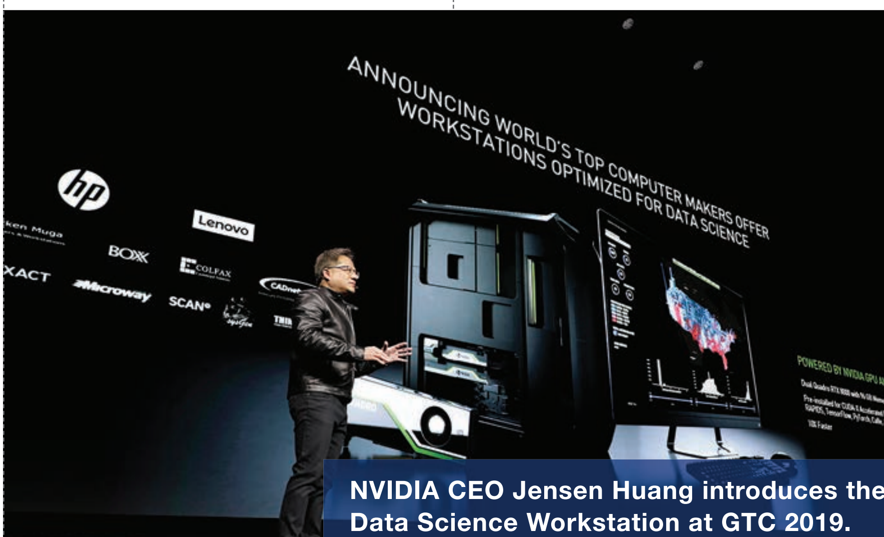
Different versions of the Data Science Workstation are expected to come from NVIDIA's partners, such as Dell, HP, Lenovo, Microway and others.

As the keynote drew to a close, Huang announced that NVIDIA Drive, the AI-powered platform for autonomous vehicle development, is now available. The latest version comes with Safety Force Field, "a computationally verified simulated algorithm" that maintains a zone that prevents collision with nearby cars, Huang explained.

The algorithm predicts the movement of nearby cars, their trajectory, and their relative speeds to ensure the AI-driven car is within the Safety Force Field.

Huang also announced the Jetson Nano, a $99 embedded computer for developing small, low-powered devices. It's a pocket member of the NVIDIA Jetson product family, embedded computers for powering autonomous machines.

**MORE** → digitalengineering247.com/r/22411




**NVIDIA CEO Jensen Huang introduces the Data Science Workstation at GTC 2019.** ***Image courtesy of NVIDIA.***

# Additive Manufacturing Users Gather to Address Challenges

**BY JAMIE J. GOOCH**

More than 2,200 people gathered in the Hilton Chicago March 31-April 4 to learn from one another, check out the latest technologies and network at the Additive Manufacturing Users Group (AMUG) 2019 conference. Like the 3D printing/additive manufacturing sector itself, the AMUG conference continues to grow. Now in its 31st year, the volunteer team of conference organizers say this was the largest conference yet.

AMUG bills itself as "the conference designed for users, by users," and the 2019 conference lived up to that billing with networking opportunities, more than 75 exhibitors and hundreds of presentations. During the conference, three topics came up again and again: materials, software and workflow challenges.

Professor Gideon Levy, who is the recipient of the 2019 AMUG Innovators Award, said additive should play to its strengths in terms of what it brings to manufacturing that conventional processes do not, such as designing internal structures, lightweighting and part consolidation.

## Materials, Machines and Models

John Dulchinos, vice president of digital manufacturing at Jabil, agreed. "It's still very early in the technology," he said. "We're in the first or second inning in an extra-inning game."

Jabil provides design, manufacturing, supply chain and product management services from over 100 facilities in 29 countries. It recently opened a Materials Innovation Center in Minnesota to deliver 3D printing material solutions under one roof, encompassing polymer formulations, compound development and ISO 9001 Quality Management System certification.

It will take time for certified materials to catch up with the thousands of certified materials available for conventional manufacturing processes. The industry is tackling that via one use case after another, certifying (and in some cases creating) materials to address real-world challenges.

"There are lots of challenges. In my work, I tend to work on the biggest challenges, and a lot of them are materials," said Chuck Hull, co-founder and chief technology officer of 3D Systems. "Imagine in production—there's not three materials, there are thousands of materials and each of them is there for a reason. That's why we say 'use case, use case,' to solve each challenge and move to the next one."

To provide one use case example, take a look at medical models.

"It used to be that the FDA's guidance was that you just had to have software that was certified," said Virginia Goble, vice president, marketing and strategy, Materialise, during an AMUG conversation. "But they recently came out with guidance that you have to have machines and materials certified to have a clinician use that. So every machine-material combination has to be certified individually."

Materialise has certified machines with Ultimaker, Stratasys, Formlabs and NewPro thus far.

"It is use case by use case," said Dave Flynn, senior business development manager, Materialise. "There are some process limitations that can be used in additive—whether it's sintering or filaments or photopolymers—not unlike injection molding in that some resins are injection moldable, some are not. The number of useful materials has certainly expanded, but we have a long way to go there."

Simulation software providers have a long way to go as well when working on the considerable challenges involved in predicting what will happen when a particular design using a particular material is 3D printed in a particular machine. Collaboration is helping the industry advance.

"What's interesting about AMUG this year is I'm finding, compared to prior years, that everyone is moving in this (collaborative) direction and it's really helped the industry. Machine manufacturers seem much more open to collaborate with all the software vendors and software vendors seem more open to having interoperability instead of trying to monopolize things. I feel that's a sign of maturity. We have to rely on each other."

## Connecting to the Digital Thread

Fast Radius is one company focused on that integration. It just raised $48M to expand its platform for production-grade additive manufacturing, which it calls the Fast Radius Operating System.

"People don't often think that additive manufacturing is a supply chain solution, but it is," said Fast Radius Chief Executive Officer Lou Rassey during an interview at AMUG. "That full thread is where innovation is happening."

Rassey is aware there are still many missing links, highlighting the gap between design and manufacturing, material preparation and formulation, operations during the build and post-processing.

"The future is like the invention of the transistor," said Levy of additive manufacturing during his time on stage at AMUG. "When it was invented, we didn't know everything it would be used for."

MORE → digitalengineering247.com/r/22485

AMUG Advisor Todd Grimm interviews Professor Gideon Levy (left), winner of the 2019 AMUG Innovators Award.

# Leveling Up

A look at the self-driving carmakers' road ahead.

**BY KENNETH WONG**

WHO IS A BETTER DRIVER: the human or the artificial intelligence (AI)? That may depend on what you mean by "better." For many AI systems, the hallmark of good driving is to be able to detect the lane ahead and place itself at the dead center of that lane. In general, this may be desirable, but there are situations where this is ill-advised.

"When you notice a pothole or a damaged road ahead, you nudge your steering wheel ever so slightly so you can keep the obstacle between your two wheels as you drive past it," points out Chris Hoyle, technical director for rFpro, a drive simulation software developer. "You want your AI system to be able to recognize these damaged roads and potholes and react in the same way."

The replication of human driving behavior—even the ill-advised swerves and lane changes of a tired, irrational driver—is important for another reason. If the virtual drivers in the simulated traffic abide by all the traffic rules and seem to know all the speed limits and lane changes with ample warnings

**With ANSYS's VREXPERIENCE software, car developers can use VR-enabled simulation to see how the vehicle's navigation reacts to different weather, traffic and road conditions. *Images courtesy of ANSYS*.**

# in Autonomy

ahead, then they're not behaving like typical human drivers. An autonomous navigation algorithm developed under these ideal conditions may not know how to react to the irrational, imperfect navigations of real humans on the road.

"It's not enough to come up with a nicely random simulation; you have to come up with hundreds or thousands of driving styles," says Hoyle.

It's neither safe nor practical to put unproven autonomous vehicles on the public road for testing. Therefore, most developers would invariably rely on simulation to make sure their vehicles can make the right decision, even in the highly unusual "edge" scenarios. The type of sophisticated simulation and training now possible suggest that moving from the current level of autonomy (Level 2+) to conditional and full autonomy (Level 3, 4, 5) is not very far off.

## What Level Are We At?

The five levels of autonomy as defined by the Society of Automotive Engineers (SAE) set up clear expectations for autonomous car developers (see page 16). The SAE's J3016 Levels of Automated Driving Chart has also been adopted by the U.S. Department of Transportation (DOT) as a policy-guiding document. It goes from Level 0: No Autonomy to Level 5: Full Autonomy.

"There's Level 2 technology in the cars commercially available today," notes Sandeep Sovani, director of global automotive industry, ANSYS. "These are advanced driver-assistance systems. In other words, the driver still has to keep full control of the vehicle; the systems merely help the driver.

Although the passenger cars are still between Level 2 and 3, the transportation industry has already surpassed them, accord-


Waymo is using the Jaguar I-Pace SUV in its self-driving car test fleet. *Image courtesy of Waymo.*

ing to Jonathan Dutton, marketing director, transportation and mobility industry, Dassault Systèmes.

"Some transportation companies are already testing and deploying small buses in geofenced regions in smart cities," says Dutton. "Today, there's generally a human operator on the bus keeping an eye on things. But these vehicles are already operating in the fully autonomous mode."

For example, with its headquarters in Lyon, France, and R&D facilities in Paris, NAVYA offers autonomous shuttle (Autonom Shuttle) and autonomous cabs (Autonom Cab). Some of its vehicles are in service in Singapore, Perth, Australia); Christchurch Airport in New Zealand; and Curtin University in Australia. Such conditional autonomy with the condition being the restricted zone will fall under Level 4 as defined by the SAE.

## The Pesky Level

For Level 0 to Level 2, the human driver is fully or largely responsible for road monitoring and making appropriate decisions. For Level 3 to Level 5, the system plays an increasingly larger role, executing dynamic navigating tasks and reacting to events. Therefore, the leap from Level 2 to 3 marks a significant breakthrough.

"Some companies are talking about skipping Level 3 and going straight to Level 4 or 5," says Sovani. "In Level 3, the human driver needs to take control of the vehicle at a moment's notice if something is amiss. But humans just don't seem capable of this kind of timely reaction."

In an article published November 3, 2017, *Car and Driver* magazine revealed, "Toyota is uneasy about the handoff between automated systems and drivers." In its online declaration titled "Looking Further," American carmaker Ford said, "[By] 2021 … [the] vehicle will operate without a steering wheel, gas pedal, or brake pedal within geofenced areas as part of a ride-sharing or ride-hailing experience. By doing this, the vehicle will be classified as a SAE Level 4 capable-vehicle." However, last month Ford CEO Jim Hackett publicly acknowledged that the vehicle's application will be limited because autonomous driving is more complex than the industry anticipated.

Part of the difficulty with designing a Level 3 car is human nature itself. Can a human be relaxed and alert at the same time? A driver may physically and mentally be capable of taking control of the car, but he or she may be highly absorbed in a game, a movie or a chat, preventing the takeover from occurring in a timely fashion.

## GPU-accelerated AI Training

Focusing on GPU-driven autonomous car development, graphics processing unit (GPU) maker NVIDIA has developed an autonomous vehicle platform. Its DRIVE AP2X Level 2+ AutoPilot uses technology from the higher levels of autonomy.

"DRIVE AP2X is a Level 2+ automated driving system. The driver is still responsible and must monitor the road, but we're also incorporating surround sensors and AI software running on deep neural networks to protect the driver and the passengers in the car," says Danny Shapiro, senior director of automotive, NVIDIA. "The technology also includes driver monitoring, and can issue alerts or take action if the driver is distracted or drowsy."

At the NVIDIA GPU Technology Conference (GTC) in March, NVIDIA announced its autonomous car simulation platform NVIDIA DRIVE Constellation is now available. It is a data center solution comprised of two side-by-side servers. The DRIVE Constellation Simulator server uses NVIDIA GPUs running DRIVE Sim software to generate the sensor output from the virtual car driving in a virtual world. The DRIVE Constellation Vehicle server contains the DRIVE AGX Pegasus AI car computer, which processes the simulated sensor data. The driving decisions from DRIVE Constellation Vehicle are fed back into DRIVE Constellation Simulator, enabling hardware-in-the-loop testing.

DRIVE Constellation is an open platform, and can incorporate many third-party world models, vehicle models, sensor models and traffic models. Recently, the Toyota Research Institute-Advanced Development, the R&D arm of the Japanese carmaker, has announced it will use NVIDIA DRIVE Constellation to test and validate its autonomous vehicle systems.

## Role of Simulation

Modern passenger cars benefit from the cumulative experience of an industry that has been crash-testing for decades. To achieve a comparable type of reliability, the connected autonomous cars must be road-tested for millions of miles. This is something that is highly challenging to do in the congested physical world, but could be accomplished in a much shorter time in the virtual world.

"The reason the current generation cars perform quite well in crash situations is because they have gone through many crashing tests in the physical environment," says Dutton.

In January of this year, Dassault Systèmes struck a strategic partnership with Cognata, which provides an autonomous vehicle simulation suite. Announcing the deal, Dassault Systèmes wrote: "By incorporating the Cognata simulation suite into [Dassault's] 3DEXPERIENCE platform and leveraging CATIA … the two companies deliver a one-stop-shop, outstanding environment to engineers for accelerated autonomous vehicle design, engineering, simulation and program management."

In 2017, Siemens PLM Software acquired TASS, an autonomous driving simulation software developer. As a result, TASS' PreScan software is now part of the company's portfolio.

PreScan is a physics-based simulation platform that is used in the automotive industry for development of advanced driver assistance systems (ADAS) that are based on sensor technologies such as radar, laser/lidar, camera and GPS, according to the company. PreScan also can work with accident information, such as road traffic accident data from the German In-Depth Accident Study (GIDAS) project.

"In PreScan, you can have a cyclist jump out in front of your car; you can change the weather from rainy to snowy to icy; and you can add more complexity to your driving scenarios," explains Andrew Macleod, director of automotive marketing, Mentor, Siemens PLM Software.

### The Role of VR

In May 2018, ANSYS acquired OPTIS, which develops optical sensor and closed-loop, real-time simulation software for car makers. As a result, ANSYS added VREXPERIENCE, an autonomous driving simulator, to its offerings.

"The VREXPERIENCE software has a suite of virtual sensors mounted on the virtual car, so as you drive your car through the simulated traffic, these sensors are capturing the road information. This represents what a real car would see when they drive this road," explains Sovani.

rFpro also accommodates the use of VR to allow developers to test their AI with real human road users in the loop. "The most cost-effective setup is for you to sit at a desk, with a VR headset providing the full 3D world, with your feet on a couple of pedals, with a steering wheel in front of you," says Hoyle. This provides a more realistic testing environment, because a 2D flat screen doesn't offer the same peripheral vision that a driver relies on for navigation.

"The VR hardware has just improved enough for this application," says Hoyle. "Earlier versions are not suitable due to weight and heat. Remember, you have to strap this device to your forehead, so if it's too heavy or too hot, it wouldn't be pleasant. The low resolution and latency in the earlier units gave users motion sickness. In VR, you can still test your AI

## Levels of Automation, Based on the Society of Automotive Engineers

| | Description | Who decides to steer, accelerate, decelerate? | Who monitors the driving environment? |
|---|---|---|---|
| Level 0:<br>No Automation | Human drives full time, handles all aspects of dynamic driving decisions | Human | Human |
| Level 1:<br>Driver Assistance | Under human supervision, system executes portions of the dynamic driving tasks | Human and System | Human |
| Level 2:<br>Partial Automation | Under human supervision, system executes accelerating, braking, and steering when activated | System | Human |
| Level 3:<br>Conditional Automation | Autonomous system can only be activated under conditions for which it was designed; requires a delay to transfer control back to human | System | System |
| Level 4:<br>High Automation | Human driver is not necessary when system is engaged; system capable of all dynamic driving tasks | System | System |
| Level 5:<br>Full Automation | System capable of unconditional full-time execution of all dynamic driving tasks | System | System |

## Dynamic driving tasks as defined by the SAE include:

- object and event detection, recognition, and classification;
- object and event response;
- maneuver planning;
- steering, turning, lane keeping and lane changing;
- acceleration and deceleration; and
- showing light, signaling and gesturing.

The simplified chart is based on the J3016 guidelines published by SAE. For comprehensive descriptions and a detailed breakdown of the roles of human and system, go to sae.org.


The A8 Highway in Germany as seen in rFpro simulation software, running a test in a scenario with cones blocking off traffic. *Image courtesy of rFpro.*

in demanding real-world situations, surrounded by real road users, but without risk of injury."

## Stay in the Safe Zone

Last October, Volvo announced it will use NVIDIA DRIVE AGX Xavier platform for its new core computer for assisted driving that will go into every next-generation Volvo. At CES 2019, suppliers Continental and ZF announced their production plans for Level 2+ systems built on NVIDIA DRIVE, with production starting as early as 2020. Mercedes-Benz also announced that its next-generation centralized computing architecture for AI in the cockpit and AI for self-driving will use NVIDIA DRIVE technology.

At GTC, NVIDIA unveiled its safety driving policy called the Safety Force Field (SFF). which is integrated into the NVIDIA DRIVE technology stack. "SFF is a robust driving policy that analyzes and predicts the vehicle's environment. It determines a set of acceptable actions to protect the vehicle, as well as others on the road. These actions won't create, escalate or contribute to an unsafe situation, and include the measures necessary to mitigate harmful scenarios," the company explains.

## Likely Scenarios for the Near Future

Before fully autonomous private vehicles appear on the road, you may begin to see highly autonomous robo taxis, with a safety driver monitoring it remotely, Sovani envisions.

"Today, the taxis have human safety drivers. But in the next few years, you'll likely see the safety driver become a remote driver. In other words, for each vehicle, there may be someone at a central control station, remotely monitoring the camera's views," according to Sovani's vision. "It will be a few years before fully automated robo taxis are commercially deployed in large numbers, as all the imaginable incidents that can occur in a driving session are too numerous for any software to account for."

On-demand mobility service providers like Uber and Lyft are interested in Level 4 and 5 autonomy. So are densely populated cities with mass transit challenges. "In that setup, I can't foresee human drivers and autonomous cars sharing the road. The mixture is not safe. What we need are vehicles that can talk to one another, and also talk to the infrastructure, such as traffic lights. But a lot of investment has to happen before we get there," says Macleod.

Looking ahead to Level 4 and 5, Macleod believes manufacturers need to make the autonomous vehicles highly customizable. A single model may not be suitable for all cities. "It would have to be batch manufacturing that's configurable," he reasons.

"Level 4 and Level 5 vehicles will have more sensors, higher resolution sensors and will require an AI supercomputer capable of processing all that data through many deep neural networks," notes Shapiro. "The NVIDIA DRIVE AGX Pegasus is the platform that many robo taxi and autonomous delivery companies are using as it is capable of processing 320 trillion operations per second."

Suppose autonomous trains, buses and robo taxis become common. Would people still want to own private cars, autonomous or otherwise? Dutton has serious doubts. "You'll always need big buses and trains to commute to work from the suburbs; and in places where you still need to go to your destination from the bus station or train terminal, an add-on transportation service can take care of it. If transportation becomes that easy, why would you want to own a car?" **DE**

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

**INFO** → **ANSYS:** ANSYS.com

→ **Cognata:** Cognata.com

→ **Dassault Systèmes:** 3DS.com

→ **GIDAS:** GIDAS.org

→ **NAVYA:** NAVYA.tech.en

→ **NVIDIA:** NVIDIA.com

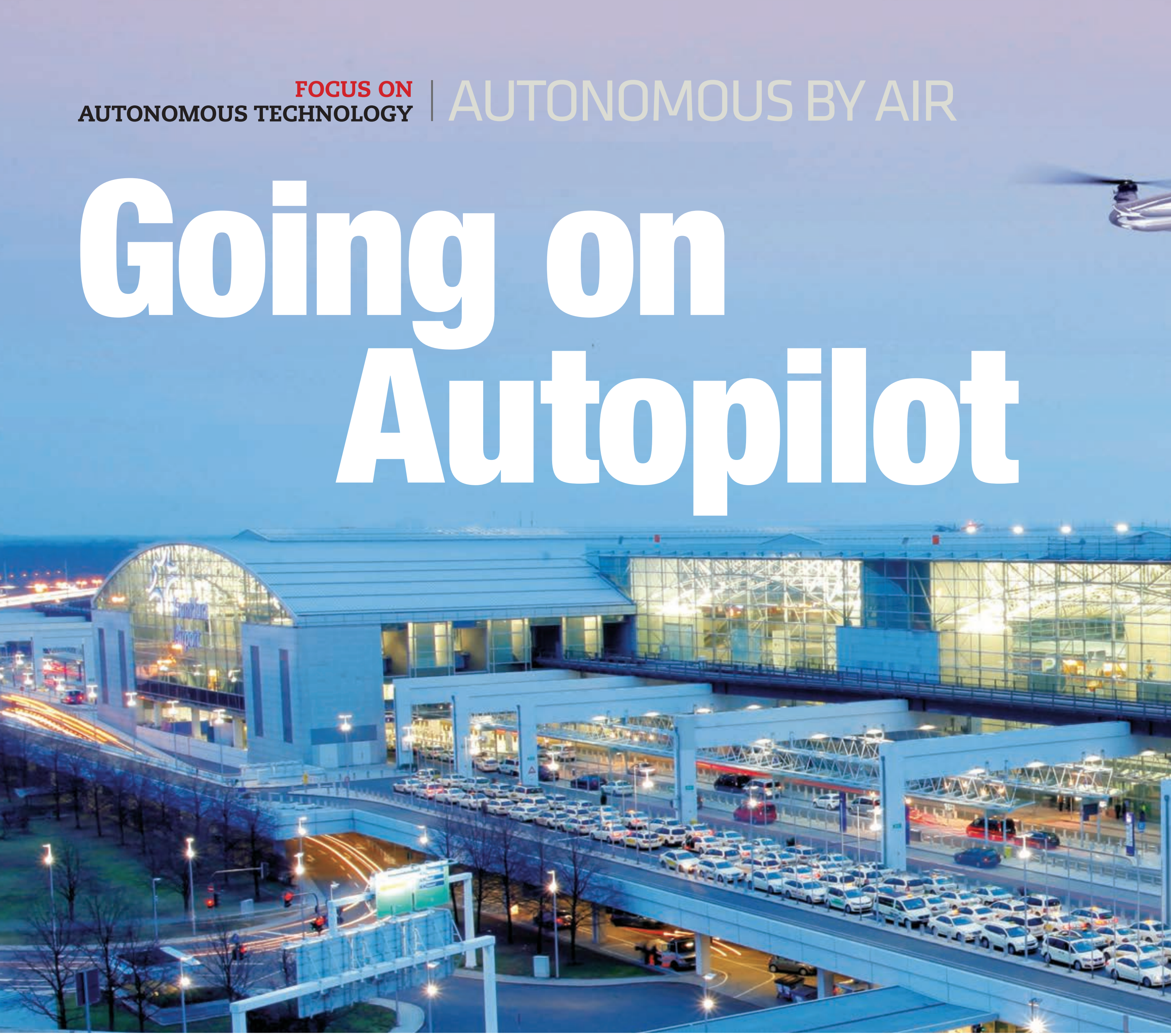
→ **rFpro:** rFpro.com

→ **Society of Automotive Engineers:** SAE.org

→ **TASS/PreScan:** Tass.plm.automation.siemens.com/prescan

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

# Going on Autopilot



## From flying taxis to cargo drones, efforts are underway to automate in the air.

**BRIAN ALBRIGHT**

WHILE AUTOMAKERS, GOVERNMENTS AND CONSUMERS grapple with what roadways will look like once self-driving cars arrive en masse, many companies are already looking ahead to what could be the next big movement in autonomous transportation: autonomous aircraft that can move both cargo and people.

Dozens of companies, from large players such as Airbus, Boeing and Uber, to small startups that are designing vertical-lift air taxis and other types of planes, are targeting the market.

Airbus has established a flying taxi testing ground in Oregon, and its CityAirbus project could demonstrate flight for its urban mobility system this year, with a fully electric 2.2-tonne aircraft. Bell has also developed an electronic vertical take-off and landing (eVTOL) using a hybrid fuel-electric approach. Boeing acquired eVTOL company Aurora and has also created an autonomous air vehicle research center in Cambridge, MA.

In January, Boeing completed its first successful test flight of an autonomous passenger air vehicle prototype in Virginia.


Image courtesy of Volocopter.

Aurora Flight Sciences designed and developed the eVTOL (part of the Boeing NeXt division), which was able to complete a controlled takeoff, hover and landing. Planned future tests will evaluate forward flight, and the transition phase between vertical and forward-flight modes.

The current prototype has an electric propulsion system and can achieve fully autonomous flight with a range of 50 miles, according to the company. The NeXt division also oversees Boeing's heavy-duty drone prototype, which can lift a 500-lb. cargo payload.

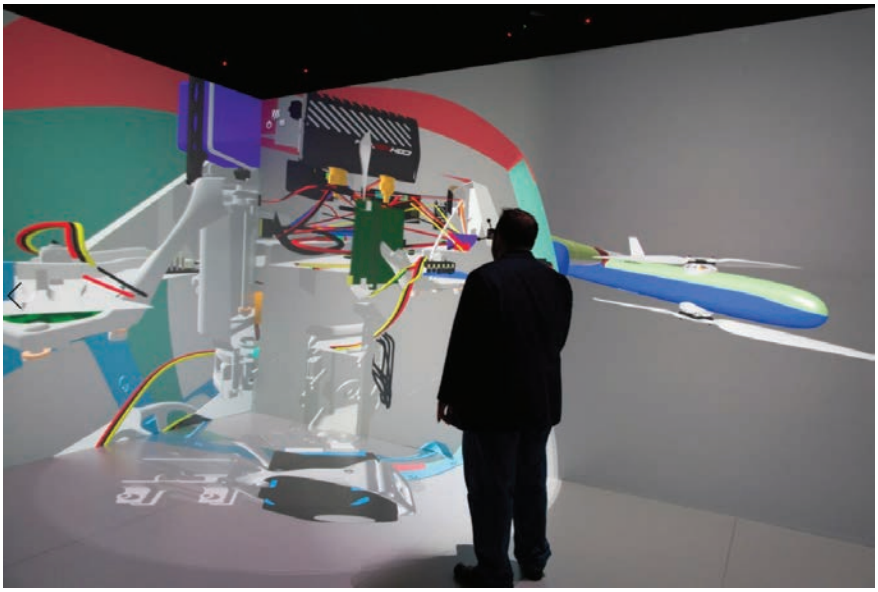
Dassault Systèmes is specifically targeting electric aircraft and sustainable air mobility through its Sky initiative. Dassault is already working with a number of aerospace companies, including air taxi startup Joby Aviation and electric passenger jet designer EViation.

"There's a lot of consumer interest, and we've seen a lot of startups investigate this air taxi space," says Eric Seiberling, geo marketing leader for North America at Dassault. "We're creating a solution that helps them cut time and development effort, and helps them get through conceptual testing and early prototyping."

To be financially viable, air taxis almost have to be pilotless—having a pilot in the craft eats up 25% to 50% of the possible passenger load, not to mention the worldwide pilot shortage. Most of these projects involve small, two-to-four-seater aircraft with electric or hybrid power sources that are designed for short-hop flights.

German company Volocopter, for example, is working with Fraport, the management entity in charge of the Frankfurt Airport, to develop plans for a potential air taxi port and hub that can link commuters to various transportation points across the city, and then to the airport.

Although consumers are not quite ready for autonomous aircraft, there is already a degree of autonomy in modern passenger and military aircraft that has helped reduce pilot workloads.



Virtual reality can be used to advance the design review process for new aircraft. *Image courtesy of Dassault Systèmes.*

"The level of automation we have already reached is very high," says Paolo Colombo, global industry director, Aerospace and Defense at ANSYS. "In a typical commercial flight, pilots pull the data into the flight computer and then spend most of the time monitoring the aircraft systems, letting the autopilot manage the flight. Manual controls are used usually just during takeoff, landing or if an anomaly is detected, and even in these phases the inputs pilots give to flight controls and engines through stick and throttle are processed by the fly-by-wire or the FADEC (Full Authority Digital Engine Control) to keep the aircraft safely into its flight envelope."

In addition to air taxi services, some startups are targeting small cargo applications and flight training.

We could see flights begin sooner rather than later, according to Siemens AG spokesperson Florian Martini. "Flight training applications have already begun, and will become commonplace within the next few years," Martini says. "Commercial transport applications will follow in the early 2020s."

## Autonomous Flight Challenges

Autonomous systems have a number of traditional engineering requirements to satisfy that are common to manned and unmanned aircraft. Endurance is a key criterion and affects a range of design considerations that are mostly electrical or new to the industry, such as materials and structural optimization, aerodynamics, electronics and propulsion systems, according to Colombo.

The need for unconventional shapes pushes designers to explore ideas that must be validated in a range of conditions including wind gusts and turbulence. Noise produced by the system must be considered as well, as it can have an effect on acceptability and certification for urban missions.

"A self-flying vehicle must also be able to sense, think and act with levels of autonomy much higher than [what's] traditionally available," Colombo says. That means the aircraft must be outfitted with a number of sensors that eat up minimal amounts of energy. As with self-driving cars, aircraft manufacturers will need to prove that these planes can safely fly in populated areas.

Power density is an ongoing issue as well, as companies struggle to find batteries that can supply sufficient energy without adding too much weight. "We [are] doing a lot of investigation into batteries that we can use in our hybrid configuration," says Ed De Reyes, CEO of Sabrewing, which is developing autonomous and semi-autonomous cargo drones. "New battery technology is really critical."

Dassault's Seiberling says that certifications will be a big challenge for these companies moving forward. "How do these companies get through that process, and document and submit everything to the FAA (Federal Aviation Administration) or other authorities to capture all of the required data?" he asks.

Noise reduction is another hurdle, particularly for companies that are targeting the urban air taxi space. Existing regulations govern where and how helicopters operate in cities; an influx of air taxis can create new noise pollution issues, as well as flight path and congestion problems.

Because prototypes and flight tests are expensive, simulation will play a big role in the development of these systems.

"Embedded software is a key differentiator as it represents the intelligence of the system, but its generation and testing under all the possible scenarios is becoming increasingly complex," Colombo says. "These considerations must be balanced against the requirements for robustness, reliability and cost. And of course, it must be demonstrated that the drone can comply with the relevant safety and regulatory requirements. This can represent years of engineering and testing, even for a large engineering team. And this is where simulation helps today, with a multiphysics approach that can consider all these phenomena together to drastically decrease the number of physical tests and support the product development and certification."

## Simulating the Future of Pilot-less Flight

That need for faster testing access and simulation capabilities is what drove the development of the Reinvent the Sky initiative. Dassault's program has helped its customers create and optimize large numbers of design concepts simultaneously, which streamlines the design space exploration process.

"You can set up model-based systems engineering and iterate very quickly, using the technology we have, and that cuts out a significant amount of time," Seiberling says. "Our 3DEXPERIENCE platform allows all of the different functions inside the smaller OEMs (original equipment manufacturers) to collaborate, as well as collaborate with partners and suppliers, and share models in real time."

Volocopter spent 10 months making calculations to confirm that manned electrical vertical flight was possible, and it took roughly a year to design the first prototype prior to the initial manned flight test in 2011, according to co-founder Alex Zosel. With several years of flight test data now available, the company is making improvements via simulation.

"We have the opportunity to integrate the data we have collected in hundreds of flights with our 1:1 prototypes into the simulation tools and software to make them ever better for our testing purposes. As a result, our simulation tools offer us extremely realistic results for the further development of our flight systems," Zosel says.

Sabrewing has conducted extensive finite element analysis and computational fluid dynamics simulations on its two autonomous cargo aircraft designs, along with independent verification and validation. The company has also used X-Plane for flight simulation. Between Sabrewing's internal team and its partners, there are nearly four dozen engineers currently working on the project.

Beyond the standard safety tests on the aerostructure, propulsion and system design, it's important to ensure that the aircraft is able to sense, decide and take safe actions in any situation that can range from traffic and weather avoidance to system malfunction management.

"This requires simulating sensors, software and controls in a loop and in a virtual scenario that creates challenges for the system," ANSYS' Colombo says. "We started doing that for autonomous driving cars, because it is impossible to physically test their systems as it will require to make them drive for more than 8 billion miles, taking hundreds of years, and we have extended our platform to test aircraft and drones."

"Simulation is the only way to manage this complexity at a cost and within a time frame that gives these project chances to succeed," Colombo adds. "Aerospace and defense companies believe they have entered an era of technology advancement that is no longer marked by linear progression, but by an exponential rate of change, and there is a consensus that digital transformation, of which simulation is a key enabler, is a critical part of how they can cope with it."

## How 3D Printing Enables Electric Flight

3D printing is also simplifying manufacture of the aircraft and reducing weight, which is especially important for hybrid and electric aircraft.

Sabrewing is using two 3D printers that work in conjunction to print the parts for both its scale models and the full-size prototype that is currently under construction.

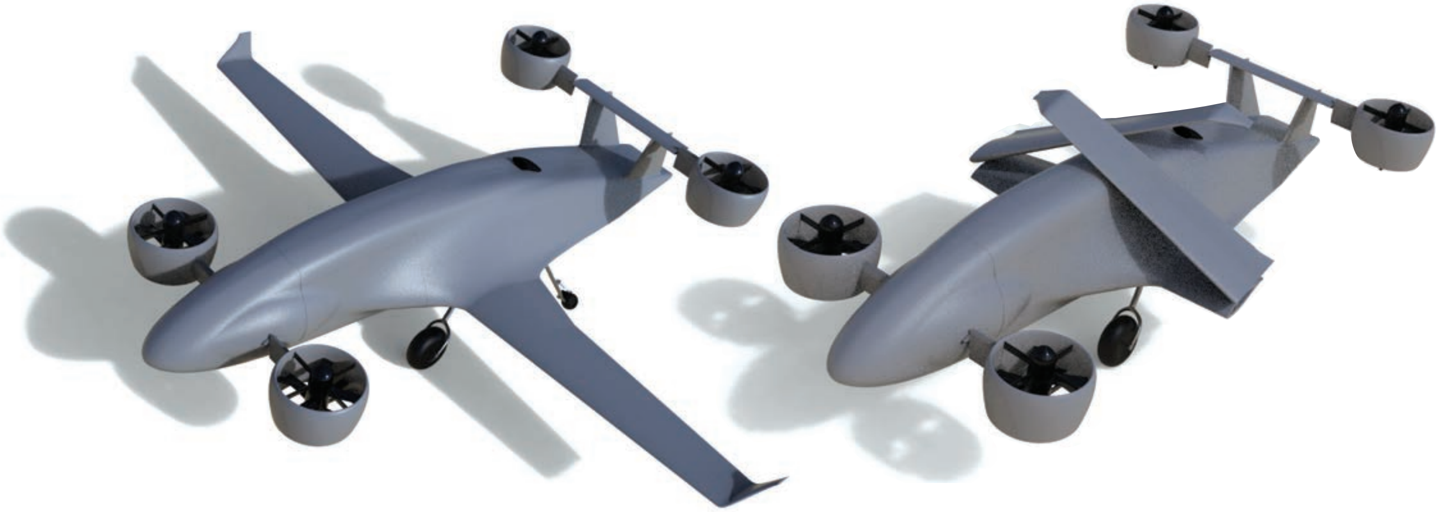
"For parts that are too large for one printer, we can split them and have dual printers running at the same time to produce the parts we need," De Reyes says. "We have quite a bit of 3D printing throughout the plane, including for our ducted fans. We can get super high tolerance parts using that process for the fans."

The Sabrewing aircraft have a frame made of composite tubes on which skins can be attached. If the skins are damaged, they can easily be replaced or repaired in the field.

"Particularly for these smaller companies, 3D printing helps get them to the first prototype without needing to spend time setting up to do traditional milling and other processes," Seiberling says. "The entire industry is looking at how to get additive out of the lab and into the production floor to make certified parts."

## Regulations Still in Flux

Exactly how autonomous aircraft will be regulated and controlled remains to be seen. Although unmanned applications like cargo transport can fall under existing FAA and other regulations that govern the use of drones, autonomous aircraft that will carry passengers will require licensing by relevant aviation authorities, as well as the



Sabrewing is designing gas-electric hybrid, remotely operated, semi-autonomous, regional cargo unmanned aerial vehicles. *Images courtesy of Sabrewing.*

development of new types of air traffic policies and controls for both airports and municipalities.

The Sabrewing cargo craft will fall under FAA Part 23, which covers anything under 12,500 lbs. "We've had a great response from the FAA," De Reyes says. "We're sharing 100% of our data with them, and figuring out together how these aircraft will be certified in the future."

"There are estimates that there could be in the neighborhood of 100 take-offs per hour or more than that," Seiberling says. "The sheer volume of air taxis could be a major problem. And where do you park and land these craft, not just in an airport but in other locations around a city? What if there is an emergency landing? These are all things that have to be sorted out before autonomous air taxis become a reality."

In the meantime, autonomous air cargo will likely see more movement over the next few years. Cargo flights don't present the same level of safety issues—there are no passengers to consider—and can operate in relatively unpopulated ground and air space, delivering goods to rural airports or even to areas that have no airports. That's a key part of Sabrewing's business model—the company is targeting military, disaster relief and other applications where cargo needs to delivered to remote areas.

It will still be a long time before we see autonomous aircraft hovering around major cities. The furor around autonomous car accidents raised additional concerns among consumers and lawmakers; a drone laden with 1,000 lbs. of cargo crash landing in the middle of a city is a disaster that nobody wants to risk.

There are other areas of opposition as well. Efforts to allow single-pilot cargo flights augmented by automation are already opposed by the Airline Pilots Associations. And automation appears to have played a significant role in the Boeing 737 Max 8 jet crashes that grounded flights around the world.

"This is actually a key question as we are missing [much] information about how to certify autonomous systems, which are the key requirements to make them fly and also how they can interact with other traffics in controlled airspaces," Colombo says. "I think that many of the companies that are developing technologies in this field are waiting for these clarifications. When they will come, we will see the real race to autonomy starting." **DE**

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**INFO** → **ANSYS:** ANSYS.com

→ **Dassault Systèmes:** 3DS.com

→ **Sabrewing:** Sabrewingaircraft.com

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

→ **Volocopter:** Volocopter.com

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## Air Force Skyborg and the Future of Unmanned Aerial Combat

If you're looking for a name that would bring to mind some of the most unpleasant science fiction predictions of future artificial intelligence gone wrong (such as the *Terminator's* Skynet AI that wanted to exterminate humanity and *Star Trek's* Borg race who wanted to turn people into cybernetic drones), you might come up with "Skyborg," which is what the U.S. Air Force is calling a program to field a prototype of an autonomous, unmanned combat air vehicle.

Unfortunate name aside, the Air Force office of Strategic Development Planning and Experimentation (SDPE) at the Air Force Research Laboratory is looking for something to show early operational capability (EOC) as early as 2023, according to a U.S. Air Force press release.

**Request for Information Issued**

In March, SDPE issued a request for information (RFI) to various industry suppliers to conduct market research and learn what is commercially available now. The RFI is the first step in determining what the current state of the art is from a technology perspective and from a systems engineering perspective to provide that EOC capability in 2023, according to Ben Tran, Skyborg program manager.

In the press release, Tran said low-cost, attritable, unmanned air vehicles are one way to bring mass to the fight when it comes to addressing potential near-peer engagements in the future. "Attritable" is military parlance for weapon designs that are low-cost and reusable, but ultimately expendable.

"Skyborg is a vessel for AI technologies that could range from rather simple algorithms to fly the aircraft and control them in airspace to the introduction of more complicated levels of AI to accomplish certain tasks or subtasks of the mission," stated Matt Duquette in the press release. Duquette is an Air Force Research Laboratory Aerospace Systems Directorate engineer with a background in unmanned aerial vehicles (UAVs) control, autonomy, and modeling and simulation.

The Skyborg AI is not scheduled to be part of any particular type of aircraft platform at this time. Tran said the RFI emphasizes the importance of an open systems architecture, system modularity and mission autonomy.

"We've partnered with the 412th Test Wing at Edwards Air Force Base, California, and specifically an organization called the Emerging Technologies Combined Test Force and we're working with them beginning with small, fast-moving UAVs to test the current state of the art in AI and autonomy in those airplanes and the ability for them to autonomously team and collaborate in flight," Tran stated in the press release.

Skyborg is running parallel to the Air Force Research Laboratory's "Loyal Wingman" program that intends to use unmanned aerial drones as sidekicks for manned pilots. The XQ-58A Valkyrie demonstrator, a long-range, high subsonic unmanned air vehicle, completed its inaugural flight March 5, 2019, at Yuma Proving Ground, AZ.

*— Jamie J. Gooch*

A Skyborg conceptual design for an unmanned combat aerial vehicle. *Image courtesy of Air Force Research Laboratory artwork.*

# Ocean Explorer Targets Terrestrial and Extraterrestrial Waters

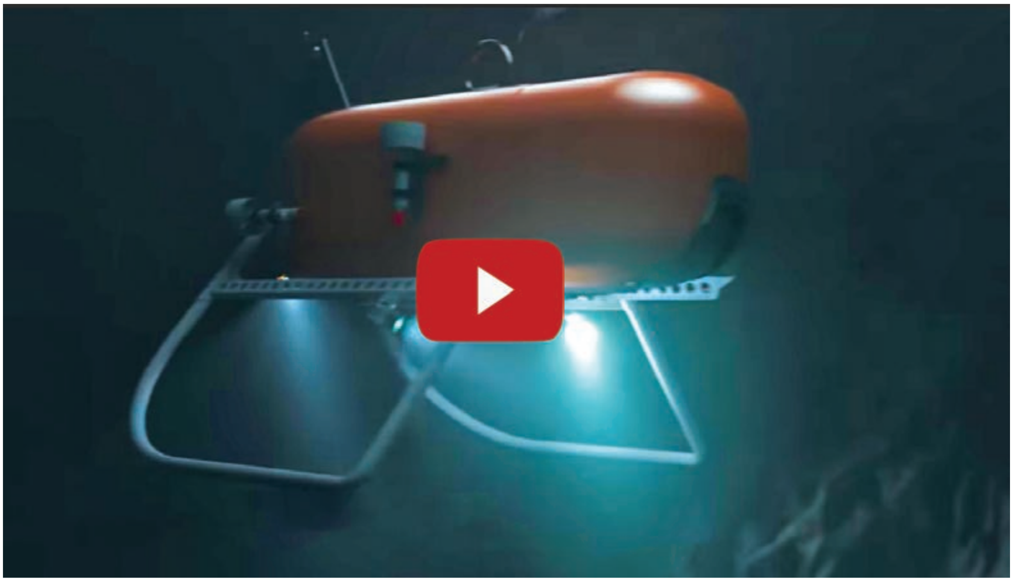
## WHOI and NASA/JPL are designing an autonomous sea drone capable of exploring the hadal zone, up to almost 7 miles below sea level.

**BY BETH STACKPOLE**

WHAT DOES THE HADAL ZONE, the deepest parts of Earth's oceans, have in common with extraterrestrial water bodies? Apparently a lot, which is why researchers at the Woods Hole Oceanographic Institution (WHOI) and the NASA Jet Propulsion Lab (JPL) have teamed up to design an autonomous drone capable of plumbing near-bottomless ocean depths for signs of life.

The 600-lb. autonomous drone made its first test dive last September, submerging 577 ft. into the ocean, still far above the target hadal zone. *Image courtesy of Woods Hole Oceanographic Institution.*

Project Orpheus is a prototype autonomous vehicle being built with the long-term goal of exploring the hadal zone, an uncharted area 6,000 to 11,000 meters (3.7 to 6.8 miles) under the sea. It's comprised of trenches and troughs and thought to be home to unknown forms of life. The pressures in the deep waters of the hadal zone map closely to the environment of extraterrestrial waters, especially those of Jupiter's Europa moon, which was the impetus for NASA to sign on as a key Orpheus design partner.



**In September of 2018, the first sea trials of Orpheus took place from OceanX's research vessel Alucia. Watch the OceanX video here: youtu.be/lwp3pCoyYMU.**

"NASA's main interest in Orpheus and related technology has to do with the ocean worlds beyond our earth that have liquid water on the surface or underneath large ice coverings," explains Andy Klesh, chief engineer for interplanetary small space craft at NASA. "If we can build an [autonomous vehicle] for finding life on Earth's oceans, we can [use it to] go and explore signs of life on distant planets."

WHOI initiated the Orpheus autonomous vehicle project after they lost their Nereus hybrid deep-ocean remotely operated vehicle on an experimental 10,000-meter dive in the Kermadec Trench northeast of New Zealand in May 2014. The vessel, which weighed more than 7,000 lbs. and cost over $5 million, likely imploded under pressure as great as 16,000 lbs. per square inch (psi) and was never recovered.

As a result of that stunning loss, the WHOI team went back to the drawing board with the goal of designing a lighter weight, simpler vehicle that would cost less and be easier to recover, according to Casey Machado, research engineer for the Applied Ocean Physics & Engineering team at WHOI and the lead mechanical engineer on the Orpheus project.

"We didn't want to lack access again, but we also didn't want to drop in a dumb platform that sinks to the bottom and floats back up with no mobility capability and just be lucky enough to land on something interesting," Machado says. "We decided to take the funding available and go back to the drawing board to regain access to the zone in a way that was beneficial to science."

## An Off-the-Shelf Design Approach

Because the available budget precluded creating a large-scale manned vehicle like James Cameron's Deep Sea Challenger, the Project Orpheus team opted for a different design strategy: Creating a lightweight, autonomous drone-like vehicle that was built using off-the-shelf commercial parts instead of expensive and often heavy bespoke components, Machado explains.

The team also wanted to build something that was accessible—not a research vessel that would require hundreds of thousands of dollars a day to operate.

As part of the early design work, Machado and team brainstormed on a white board and then translated those early concepts into 3D CAD models for further iteration. Whenever possible, they chose to spec hobby- or commercial-grade components along with a significant reliance on open source software, such as an aquatic open source program that mimics what is used for aerial drones, she explains.

"All the fundamental things the vehicle has to do—drive around or turn lights or cameras on and off—all that foundational functionality is accomplished through open source software," Machado says. "From there, anyone can do what they want in terms of adding complexity."

To survive under ambient pressure conditions of up to 16,000 psi, Orpheus' lightweighting goals required system components to be strong enough to withstand pressure on their own as opposed to employing sealed atmospheric enclosures for protection—a design choice that significantly increases vehicle weight.

The team substituted a much smaller 17-in.-diameter glass sphere, which serves to wall off and protect any components—batteries, for example—that can't be exposed to sea water

## Setting Sail Autonomously

In January, Leidos announced that the Office of Naval Research (ONR)'s Medium Displacement Unmanned Surface Vessel (MDUSV), Sea Hunter, became the first ship to successfully autonomously navigate from San Diego to Pearl Harbor, HI, and back without a crew member onboard, except short duration boardings to check electrical and propulsion systems.

Leidos designed and built the 132-ft.-long Trimaran, Sea Hunter, which it says is the first autonomous, unmanned vessel capable to travel for long periods of time and execute a variety of missions at a fraction of the cost for a manned ship.

"The Sea Hunter program is leading the world in unmanned, fully autonomous naval ship design and production," stated Gerry Fasano, Leidos Defense Group president via a press release. "The recent long-range mission is the first of its kind and demonstrates to the U.S. Navy that autonomy technology is ready to move from the developmental and experimental stages to advanced mission testing."

Sea Hunter will continue long duration and mission package testing throughout 2019. ONR awarded Leidos a potential $43.5 million contract to develop Sea Hunter II, which is currently under construction in Mississippi. The sister ship will be updated based on lessons learned during the first Sea Hunter build, evolving mission requirements, and further development of autonomy enhancements.

"Our talented team of engineers, scientists and analytical experts have decades of experience that will allow us to deliver a second highly autonomous vessel designed to keep our servicemen and women safe while monitoring the maritime environment," said Fasano via the release.

*Navy photo by John F. Williams.*

without adding substantially to the structure. Thanks to the lightweighting and off-the-shelf parts strategies, the current Orpheus prototype tips the scale at just under 600 lbs.

JPL/NASA's principal contribution to Orpheus is the autonomy, vision software and control electronics, with much of the algorithms adopted from what was developed for the Mars missions. JPL/NASA also contributed to the miniaturization work, specifying off-the-shelf commercial components used in toasters, cars and cell phones, Klesh says.

By applying the same commercial off-the-shelf technology used in drones to the autonomous vessel, the JPL/NASA and WHOI teams were able to significantly lightweight Orpheus, which will be essential when some version of the autonomous vehicle is deployed for space ocean exploration some point down the line.

### Adding Autonomy

In addition to the JPL/NASA artificial intelligence-driven image processing capabilities, sensors and cameras are key to Orpheus' intelligence and autonomy. The combination helps the vessel navigate on its own and recognize if it has traveled somewhere before—an achievement that will be essential for future generations, which are being developed to work as an autonomous drone fleet both within Earth's ocean depths and in space waters.

If you couple the image processing intelligence "with capabilities for sensing water chemistry, temperature or biological sensing, you have a recipe for how to look and find life in the ocean," Machado says. "Orpheus can fly around in autonomous mode, sense various chemicals or venting hot fluid, and determine what the source is."

Although still quite sophisticated, autonomous operation in the ocean is less onerous than creating systems for land vehicles like cars, according to Ahmad Haidari, global industry director at ANSYS. "From a design perspective, both have safety and reliability concerns, but the consequences are different," he explains.

Because of all the permutations in an on-road scenario, such as pedestrians crossing the road or being cut off by another vehicle, he says, simulation is central to understanding the full environment. "There are so many permutations that [physical] testing this would be impossible," he explains. "Simulation takes what's happening on the vehicle and what's happening in the environment and puts it together."

### A Hands-on Approach

Apart from the complexities developing the autonomy capabilities, WHOI used a more hands-on approach to building and testing the physical Orpheus components. The team made liberal use of WHOI's fabrication department and machine shop to produce the bulk of componentry in-house.

In lieu of robust simulation and analysis, the WHOI team used "back of the envelope" calculations to estimate drag and

**NASA/JPL, WHOI's collaboration partner, sees Orpheus laying the ground work for autonomous drone exploration of oceans in space.** ***Image courtesy of Woods Hole Oceanographic Institution.***

figure out battery and power requirements, Machado says.

"Doing computational fluid dynamics (CFD) is time-consuming and can be really expensive. In this case, we could learn quite a bit just by putting Orpheus in the water and seeing what happens," she says. "When you're building a submarine that costs millions of dollars, there's a higher risk threshold."

In September 2018, researchers launched Orpheus' maiden voyage in the waters outside of Cape Cod Bay. The goal of the first expedition was limited in scope: Get the vehicle in the water, ensure the four cameras and data collection systems worked, and test a key aspect of its autonomous mission—the release of steel weights that fall to the sea floor so the drone will surface for recovery.

With the initial expedition deemed a success, WHOI and JPL/NASA are pursuing their joint mission to evolve the current Orpheus into a next-generation autonomous vehicle capable of extraterrestrial exploration.

"Think of this as the great, great, great, great grandfather or grandmother of what we will eventually set out to do on Jupiter's Europa moon," Klesh says. "We are evolving the technology and techniques and learning through this, but it's certainly a far-away descendant." **DE**

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**INFO → ANSYS:** ANSYS.com

→ **NASA Jet Propulsion Lab:** JPL.NASA.gov

→ **Woods Hole Oceanographic Institution (WHOI):** WHOI.edu

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# KICKING THE TIRES ON DIGITAL TWINS


Digital twins are increasingly important to automakers and other large enterprises, but SMBs can make use of them as well. *Image courtesy of PTC.*

## The benefits of virtual representations of individual physical assets aren't just for large enterprises.

**BY KIP HANSON**

IMAGINE DESIGNING A WEARABLE DEVICE that reports your heart rate and blood pressure to your cardiologist. How about cement that warns hydroelectric dam operators of increased stress levels, a robot that lets the maintenance crew know when they should order a replacement servo motor or a shopping cart that reads the grocery list on your smartphone and helps you find the canned peas?

Welcome to the Internet of Things (IoT). Anyone who's read about it has already heard about these intriguing possibilities, but what they might have missed is how IoT sensor data from planes, trains and automobiles can be applied to digital replicas of these objects, then used to predict and improve their performance.

It's called a digital twin, and whether your company has 10 employees or 10,000, think of a digital twin as a living,

**"Digital twins are not an all-or-nothing proposition. Practically speaking, you only need subsets of relevant information to drive initial use cases, not thousands of data points."**

– Dave Duncan, PTC

breathing, but entirely virtual, replica of a manufactured product. It could be one of the products just mentioned, or it could be some widget that a startup company like yours has recently developed, one that will surely leapfrog the competition if you can collect accurate, real-time usage data.

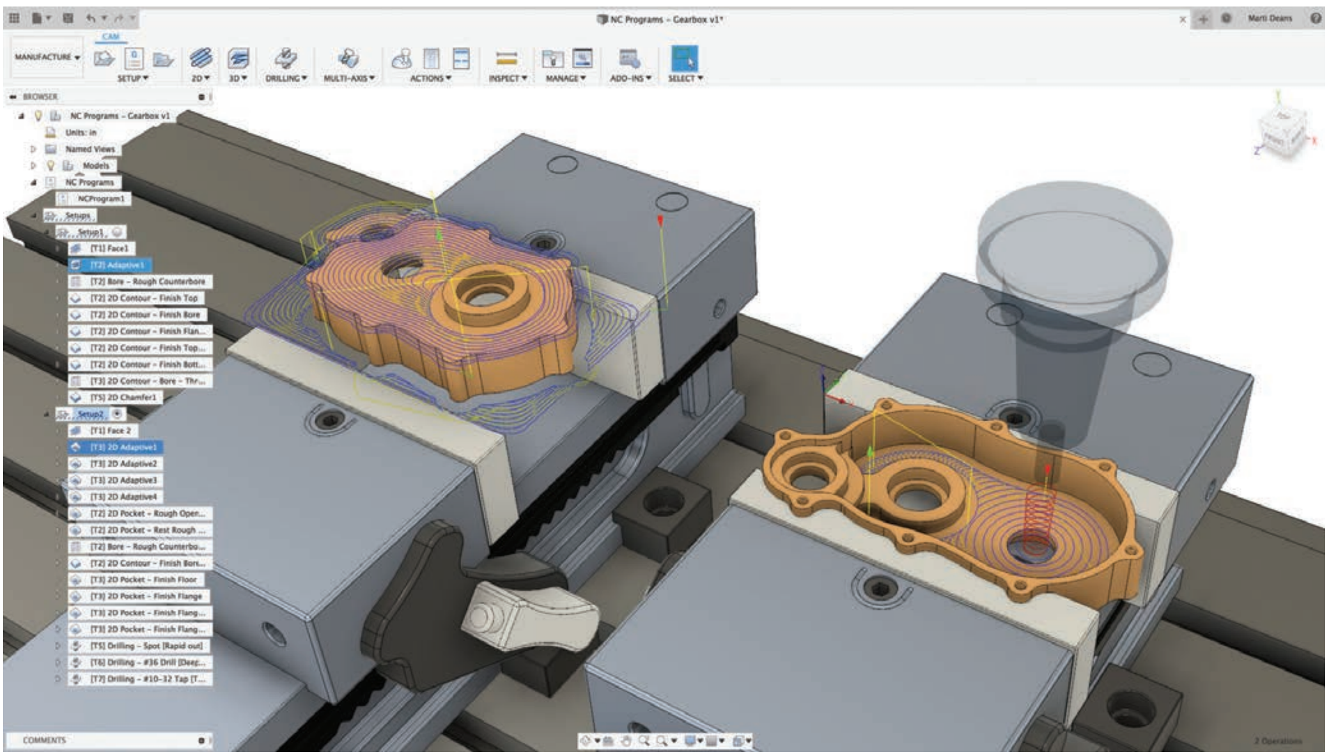
Whatever the case and whatever the scale, digital twins allow designers to collect and analyze data from their "as-manufactured" products and compare to their "as-designed" 3D models. Properly implemented, digital twins provide a wealth of information: predictive maintenance becomes more predictable, product safety and durability improve and development costs go down. And one day soon, digital twins will be as common as CAD models, without which no company large or small can long survive.

## But What Exactly is a Twin?

Unfortunately, the term digital twin is still nebulous, especially to small- to medium-sized businesses (SMBs) who don't have fleets of technical experts around to explain what it is and how to leverage it. One definition comes from Deloitte Consulting LLP, which in a recent white paper (https://bit.ly/2D5bE7s) described digital twins as "an evolving digital profile of the historical and current behavior of a physical object or process that helps optimize business performance."

Aaron Parrott, a managing director with Deloitte Consulting LLP's Supply Chain and Network Operations practice, says digital twins can "simulate specific complex deployed assets such as jet engines and large mining trucks in order to monitor and evaluate wear and tear and specific kinds of stress as the asset is used in the field," adding that the information gleaned from these and other digital twins will almost certainly affect future product designs by providing hitherto unavailable insights into their performance in the field.

Yet Rahul Garg, vice president of mid-market at Siemens PLM Software, offers a broader, three-pronged definition. "We like to think of the digital twin in holistic terms," he says. "From the design perspective, a digital twin assures that all of your analysis, simulation, prototyping and testing can be done digitally, streamlining the entire engineering process. Then there's the digital twin for production, which allows manufacturers to evaluate and manage all of their different processes, quite possibly using factory floor data to improve product design. And of course there's the more classical



**Toolpaths and other relevant information from the production floor is often fed back to the digital twin, giving designers an opportunity to improve manufacturability.** ***Image courtesy of Autodesk.***

Digital twins make self-driving cars and other advanced automotive concepts safer and more cost-effective to develop. *Image courtesy of PTC.*

definition of digital twinning, where IoT-based technologies are used to provide performance data from the field."

## Closing the Loop

Garg says this third version of the digital twin can generate significant advantages to companies that wish to increase proactive maintenance activities, because historical tracking of performance data from the pumps, motors, controllers and other components found in a typical mechanical assembly—especially when collated across hundreds or thousands of such assemblies—provides a fairly reliable prediction of future performance. When that same data is applied to the digital twin, however, the advantages exponentially grow.

"You also have to consider solutions like virtual commissioning, which make it very easy to develop and evaluate the automation model, the electrical model and the physical and kinematic model as a digital twin, and ensure that when you build the real machine, it will behave and function like its digital twin," Garg says. "The result is an iterative loop of continuous improvement, not only of the product itself, but of the manufacturing processes associated with it. This is what makes the digital twin truly transformative."

For an SMB concerned about securing funds or hitting the next project milestone, all this talk of feedback loops and business transformation might seem overwhelming. Yet Dave Duncan, vice-president of PLM and connected engineering at PTC, explains that a digital twin initiative doesn't have to be difficult.

"Digital twins are not an all-or-nothing proposition," Duncan says. "Practically speaking, you only need subsets of relevant information to drive initial use cases, not thousands of data points.

"For instance, you don't need machine-based sensors or even a whole lot of technical sophistication to collect the 'as-built' bill of materials from the production floor, and electronically tie that to the upstream CAD/eBOM (engineering bill of materials) definitions for use as a reasonable approximation of the fielded asset configuration. You can drive a lot of enterprise change planning, closed-loop quality and data-driven design use cases from this fast starting point. This is a simple but useful example of digital twinning, incepting a program that can build upon over time as business systems and connected product data improve."

## Stuck in the Middle

But perhaps you don't have a production floor. Many SMBs subcontract their manufacturing to others, and then sell their wares to service providers or original equipment manufacturers, who then assemble those products into an appliance or motorized vehicle of some kind. What opportunities do digital twins offer to those stuck in the middle?

Duncan says end-use data collection can be challenging for these companies, but that mechanisms can and should be introduced during the design phase to assure that information is shared in both directions. Subcontractors must be willing to provide manufacturing data such as material specifications and test results for inclusion in the product designer's digital twin. And provided the product is equipped with wireless sensors and has regular access to the internet (a basic tenet of the IoT), feeding performance data back to the designer should be no big deal— however, it often is.

For example, an automobile should be a perfect scenario for the digital twin today, says Duncan. However, vehicle service is typically provided by independent vendors, so it can be difficult to get relevant data back from the equipment owners or the car dealers.

"This is changing over time as manufacturers offer more services to subscribe product connectivity with their value chains," Duncan adds. "A well-known example is Tesla's over-the-air update program that delights their customers—most voluntarily subscribe. Programs like this that offer capability, convenience or risk share to the downstream value chain are enhancing digital twins for the manufacturers."

**Capturing real-world data and tying it back to the design intent is one of a digital twin's many benefits.** *Image courtesy of Siemens PLM Software.*

## On the Factory Floor

This situation will obviously change as the manufacturing industry embraces and then insists upon compliance, but in the meantime, there remain plenty of opportunities for SMBs of all stripes to leverage the digital twin.

"It could be something as simple as a toolpath simulation, where machining data can then be tied to the digital twin for performance analyses," says Al Whatmough, CAM product manager at Autodesk. "On the other end of the spectrum, there's digital twinning of the factory floor, which gives industrial or manufacturing engineers greater ability to optimize their entire operation."

Sanjay Thakore, business strategy manager at Autodesk agrees, although he's quick to point out that the latter of these two examples is generally not found in an SMB. "Large-scale models of factory layouts like these are typically more prevalent in enterprise-class businesses, where they have teams dedicated to modeling the factory and all its equipment, and the ability to install sensors wherever they're needed," he says.

## Looking Ahead with AI

Does that mean SMBs should hold off on a digital twin initiative? Not at all. Breaking down such initiatives into smaller incremental goals is a good starting place, Thakore suggests. Examples could be eliminating manual programming of computer numerical control machines or digitizing factory floor processes.

Once in a digital environment you can begin comparing post-manufacturing data to what the software initially predicted and create feedback loops—a product lifecycle management (PLM) system might reference various aspects of a digital twin's history, while artificial intelligence (AI) could analyze this and other parts of the digital twin to predict when and how a product will fare years from now.

Partly due to increasingly affordable cloud computing and software as a service (SaaS), Thakore explains, these tools and more are available to even the smallest small business, making some level of digital twinning a possibility for all. "Whatever the company's size, a digital twin environment promotes greater connectivity between the design team and the manufacturing floor," he says. "Even though you might not be putting IoT-capable sensors in your products anytime soon, digital twins bring a lot of value to the table. There's really no reason to wait." **DE**

**Kip Hanson** *writes about all things manufacturing. You can reach him at kip@kahmco.net.*

**INFO** ➜ **Autodesk:** Autodesk.com

➜ **Deloitte:** Deloitte.com

➜ **PTC:** PTC.com

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

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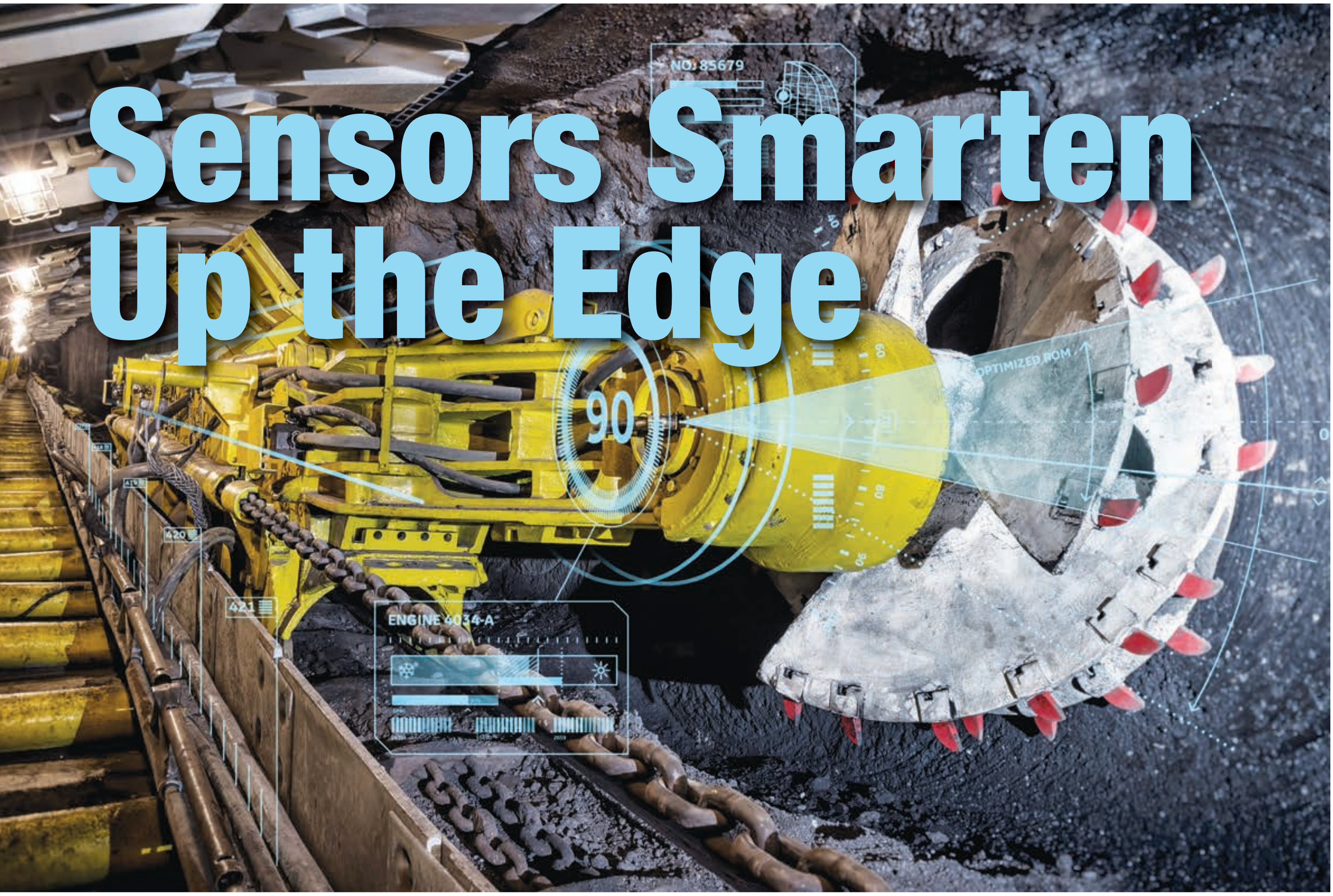
# Sensors Smarten Up the Edge




Companies that want to bring AI to the edge face hardware and data processing challenges.

**BY TOM KEVAN**

THE EMERGENCE OF UBIQUITOUS sensing and the Internet of Things (IoT) has sparked a migration of advanced processing, memory and communication resources to the network's edge. In the process, these trends have caused a shift away from simple sensors to smart sensors, a move toward deploying greater intelligence at the data source.

Yet the chain reaction does not stop there. Developers and users have started to push for analytics and the ability to perform more complex applications at the sensor level, due to the presence of more robust systems at the edge. This means giving smart sensors more muscle. Most recently, moves to enhance sensor capability have led to implementations of various forms of artificial intelligence (AI) in smart sensing systems.

Keeping up with the evolution of sensors' role at the edge and the need to bolster the devices' capabilities have challenged design engineers to develop new systems and rethink the application of more established technologies.

## Sensors' Role at the Edge

The intertwining of smart sensing, analytics and artificial intelligence in the evolution of edge systems makes sense. Armed with greater intelligence, smart sensors offer significant advantages. By processing data locally, these systems reduce the bandwidth used to interact with the cloud, enhance security, increase safety in time-critical applications, and reduce latency and enable real-time decision-making.

"By essentially turning sensors into little computers, they become a great tool for the Internet of Things," says Rochak

← **The infusion of analytics and AI into smart sensors residing on the networks edge is proving to be a game changer, opening the door for real-time automated control and decision-making, enhanced security and improved safety in time-critical applications.** ***Image courtesy of GE Digital.***

Sharma, senior director, Predix product development, at GE Digital. "Not only are they able to gather the data, but they also convert that data into meaningful insights by using their data processing and analysis abilities."

Although smart sensors have been in play for years, technology developers are still sorting out how sensing devices fit into the IoT environment. That said, a number of visions have surfaced.

One such view anticipates an inclusive, global fabric. "We expect the system to consist of many smart sensors that interact locally with each other—we call this the 'extreme edge level'—but also with multiple edge devices that interact with each other and with local cloud servers, eventually up to the real global cloud server," says Rudy Lauwereins, vice president of digital and user-centric solutions at IMEC.

Other industry leaders envision a system with more limited interaction between smart sensors and the cloud. "Having been extensively involved in fingerprint and heart-based sensing/access control, I can add that there is a desire not to rely on the cloud for security-sensitive applications and applications like automotive, where the cloud may not always be available," says David Schie, CEO and cofounder of AIStorm.

## New Demands on Smart Sensors

Before moving forward, designers must determine whether smart sensors have the resources to fully support advanced analytics, including the current selection of AI offerings.

A look at what edge systems need to perform more complex applications reveals that the limitations of processors, memory and long-term storage do not meet the future needs of smart sensor designers. Next-generation systems must have greater integration, speed, flexibility and energy efficiency.

Some contend that this feature set will require enhanced sensing technologies, new types of processors and compute architectures that break with traditional concepts and blur the lines between conventional computing system elements.

## Sensor Fusion Challenges

Sensor fusion is one area requiring further development to help smart sensors better support edge analytics. As with many tasks performed at the edge, timing is everything, and fusion is best performed sooner rather than later.

"Smart sensors need to perform analytics directly on the raw data of multiple sensors to come to a decision instead of what happens today. Every sensor performs its own analysis and makes a decision, and that information is then compared with the conclusions of other sensors," says Lauwereins. "Doing early fusion increases the accuracy of detection substantially."

The challenges involved in improving sensor fusion—as with many other compute-intensive applications—highlight the need for new and better processor-memory architectures.

## Choices and Tradeoffs

Today, digital processing architectures dominate the smart sensor and embedded system sectors, fielding such technologies as graphics processing units (GPUs), field-programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), systems on a chip (SoCs) and CPUs. When picking the most appropriate platform for a smart sensor application, the designer must juggle a number of criteria. These range from the type of analytics to be performed, environmental constraints and energy budgets to programming flexibility, throughput requirements and cost.

Each processing hardware has its own strengths and weaknesses, which forces the development team to make tradeoffs. A close look at the application's requirements often steers the designers to the best choice.

"If latency is the key criteria, then the use of an FPGA or ASIC trumps GPU because they run on bare metal and so are more suitable for real-time AI," says Ramya Ravichandar, vice president of product management at FogHorn. "In situations where power consumption is critical, FPGAs tend to consume less power than GPUs. In comparing ASICs and FPGAs, the former have longer production cycles and are more rigid in terms of accommodating design changes. In this regard, GPUs are probably the most flexible because one can manipulate software libraries and functions with much quicker turnaround time."

In addition to having to contend with the tradeoffs, designers must also find ways to accommodate other issues. For example, GPUs are designed for uncorrelated data applications while sensors are suited for correlated-data applications. This conflict can impact processing efficiency.

"Research has shown a loss of 70% to 80% of processing capability for a GPU-based approach due to the difficulty of breaking up problems into chunks that can be sent to a huge number or parallel processors," says Schie.

One constant in this area, however, is that the leading digital platforms are works in progress. Chipmakers serving the edge know the shortcomings of the latest generation of processors; these companies are constantly upgrading their offerings and tailoring processors to better serve the edge.

"SparkFun's new edge development, based on a collaboration with Google and Ambiq, supports TensorFlow lite and is priced around $15," says John Crupi, vice president of edge analytics at Greenwave Systems. "NVIDIA just announced a GPU-based edge board called Jetson Nano for $99. And Qualcomm's AI Engine runs on its newer generation Snapdragon-based boards. Ultimately, the best processor type will depend on power requirements, cost and use cases."

## One Way to Eliminate the Bottleneck

As impressive as the advances in the digital sector are, some developers have begun to look beyond conventional technology to explore new types of processors and computing architectures.

In their search, designers increasingly place a premium on technologies that promise to deliver high throughput and excel at handling the large amounts of raw data generated by sensors at the edge. Furthermore, the introduction of AI has increased the need for greater processing speed.

At the heart of the problem lies the von Neumann bottleneck—a limitation on throughput caused by latency arising from the need to transfer programs and data from disk storage to the processor. This architecture has increasingly proven to be an obstacle in real-time performance and power consumption.

"Today's GPUs come close to 100 TOPS, which is the compute level needed for real-time pedestrian recognition in video or for sensor fusion between RGB video and radar images," says Lauwereins. "However, this comes at a power consumption of 200W to 300W, which is OK for a cloud server, but not for automotive, where you would need 10W to 20W. If you go to the mobile arena, the power envelope is 100mW up to max 1W, and for battery-operated IoT devices, the range is 1mW to 10mW."

To sidestep these obstacles, a number of technology developers now advocate an approach called in-memory computing, which calls for storing data in RAM rather than in databases hosted on disks. In this approach, memory essentially performs double duty, handling storage and computation tasks.

This precludes the need to shuttle data between memory and processor, saving time and reducing energy consumption by as much as 90%. In-memory computing can cache large amounts of data, greatly speed response times and store session data, which helps to optimize performance.

"We need to evolve to a new type of computing platform, where we lose less power in moving data up and down to the compute engine," says Lauwereins. "We need to compute in memory, where the data stays where it is stored and can be processed at that same place."

## Processing Goes Analog

Another approach to smart sensor and edge analytics implementations focuses on an area that promises greater efficiency: analog processing. The catalyst for these development efforts stems from the fact that the leading processor contenders—namely GPUs, FPGAs and ASICs—require a digital data format.

The catch here is that sensor output naturally comes in analog form. This means that digital systems require data to go through an analog-to-digital conversion process, which can increase the system's latency, power consumption and cost.

To address this problem—and to facilitate inclusion of AI in smart sensors—companies like Syntiant and AIStorm have chosen to provide analog data chips.

In general, analog processors solve problems by representing variables and constants with voltage. The systems manipulate these quantities using electronic circuits to perform math functions. For example, designers can use analog multipliers, exploiting the current/voltage relationship of the transistor to perform math. They can also use memristors and resistive RAM, where resistances are programmed as weights.

Another technique involves using switched capacitor circuits, where the system manipulates capacitor arrays to produce gain. In the case of AIStorm, the company has patented a charge domain approach, where the system multiplies electrons rather than voltage or current.

AIStorm has designed its AI-in-Sensor SoC to be integrated in smart sensors that target low-power applications. The SoC aims to achieve high throughput and energy efficiency by processing sensor data in its raw analog form without encoding it in a digital format. The company claims that the analog data can then be used to train AI and machine learning models for a wide range of different tasks, achieving greater efficiency than a digital system.

## Then There Is Memory

Paralleling moves to take processing into the analog realm, some edge analytics and AI developers advocate implementing analog memory to achieve greater performance and energy efficiency.

"This approach stores information in an analog way," says AIStorm's Schie. "For example, analog floating gate memory can store the equivalent of eight bits in the space that digital uses to store a single bit. Basically, charge is added or removed, and the actual charge level is considered instead of a digital zero or one."

Examples of this memory include the y-flash from TowerJazz and SONOS embedded flash memory from Cypress Semiconductor.

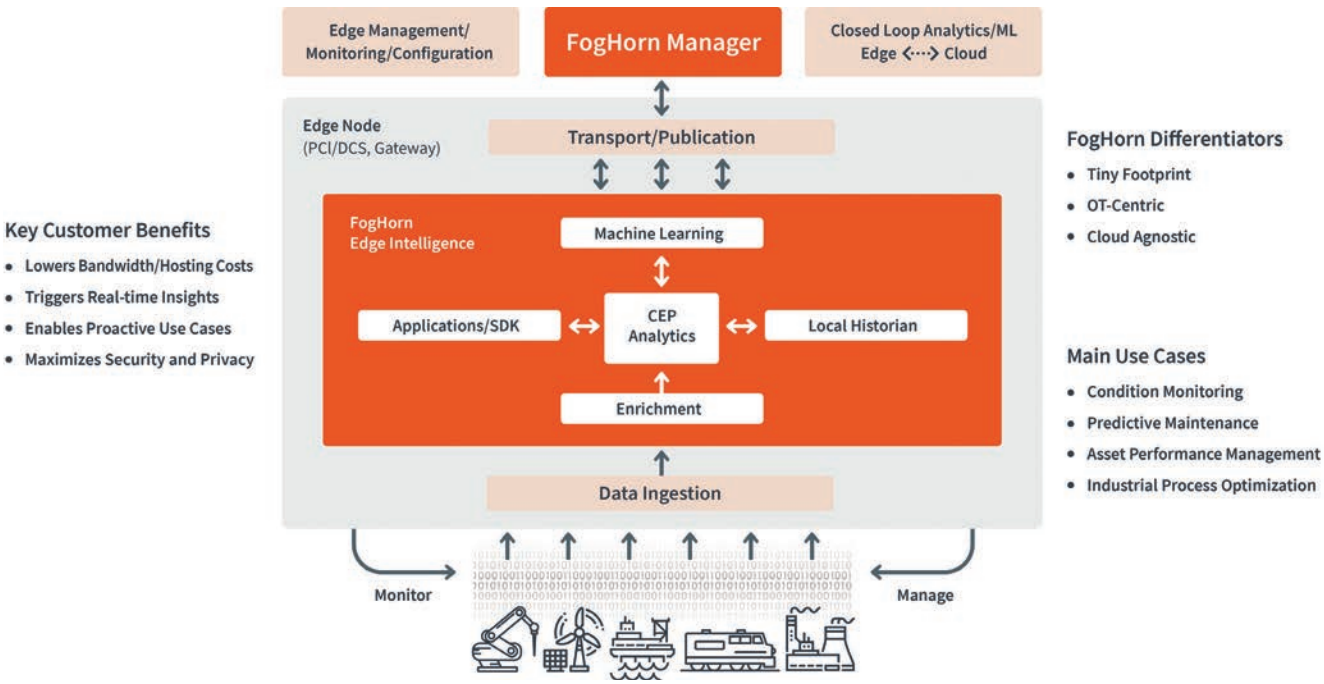
## Tools for the Edge

Smart sensor development that can perform edge analytics, including AI, presents a unique set of hardware challenges. That said, creating the software for smart sensors can be very complex. Even engineers with a high-level software training experience difficulties.

The edge is very different in terms of servers because the memory available is extremely limited and the data is not correlated. As such, architectures and tools that work well in an environment of near-limitless memory and processing, such as the cloud, do not transplant well.

"The key is to understand that edge computing technology has evolved to the point that focus can be placed on the analytic instead of starting at the board support package and building an entire software stack in-house," says Joel Markham, chief engineer for embedded computing at GE Research.

"The use of container technology, for example, to quantize applications into microservices offers a key benefit to those wanting to deploy smart sensors in that the care and feeding of these systems can be captured in reusable modules that can service the smart sensor and the application throughout its lifecycle. This use of micro-services also means that the rest of the edge analytic can be assembled, tested and deployed more effec-




**Designed to bring intelligence to the edge, FogHorn Systems' edge lighting software promises to support sensor fusion, simultaneously processing multiple streams of different types of data. In addition, the company says the 2.0 version of the software supports the Predictive Model Mark Up Language, which enables compliant machine learning models to be run at the edge.** ***Image courtesy of Foghorn Systems.***

tively in just about any measure you wish to impose."

Complementing this approach, myriad tools from the various platform vendors can create the basic building blocks of smart sensor applications. For example, open-source tools can train a given model or build an analytic for subsequent optimization and execution on the selected hardware.

Some of these tools bridge the gap between existing development platforms and the new demands arising in smart sensor, analytics, and AI design. "There are many tools already being used to develop and expand our understanding and use of AI and machine learning," says Wiren Perera, senior director of IoT strategy at ON Semiconductor. "In terms of the edge, cross-compilers enable the use of existing software algorithms/IP. These are perhaps one of the most relevant and important today."

A new generation of such tools is also in the works that takes this approach one step further. "Code collaboration tools and compilers are needed, and companies such as SensiML, which was acquired by Quicklogic, are starting to explore this space with automatic code generation tools virtualized on powerful servers that generate code that is then pushed to the edge," says Marcellino Gemelli, director of global business development at Bosch Sensortec.

## Perspectives and Prospects

All of these hardware and software challenges make smart sensor development a daunting task. Even with today's tools, designers can feel hamstrung. Perhaps the greatest challenge for the designer, however, is achieving the right state of mind.

"In many cases, the challenge is how developers think about the problem when faced with an underlying platform that gives them this many degrees of freedom," says GE's Markham. "Developers are going to need to expand their thinking." **DE**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**INFO ➜ AIStorm:** AIStorm.io

➜ **Ambiq:** Ambiqmicro.com

➜ **Bosch Sensortec:** Bosch-Sensortec.com

➜ **Cypress Semiconductor:** Cypress.com

➜ **Foghorn Systems:** Foghorn.io

➜ **GE Digital:** GE.com/digital

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➜ **Greenwave Systems:** GreenWaveSystems.com

➜ **IMEC:** IMEC-int.com

➜ **NVIDIA:** NVIDIA.com

➜ **ON Semiconductor:** ONsemi.com

➜ **Qualcomm:** Qualcomm.com

➜ **Quicklogic:** Quicklogic.com

➜ **SensiML:** SensiML.com

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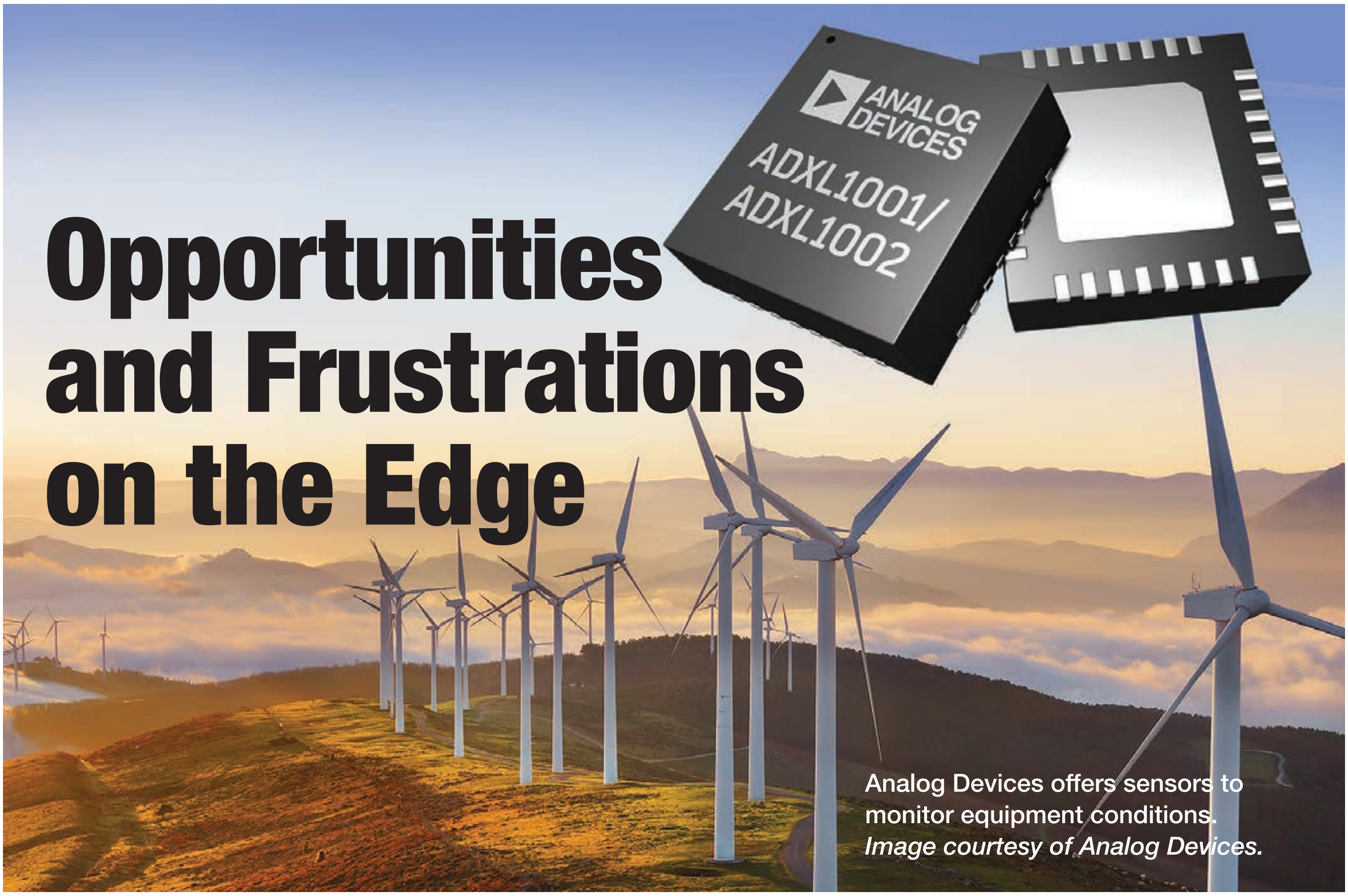


# Opportunities and Frustrations on the Edge

Analog Devices offers sensors to monitor equipment conditions. *Image courtesy of Analog Devices.*

Balancing quality and quantity of edge data presents a difficult challenge.

**BY KENNETH WONG**

IN REAL LIFE, we prize the judgment of people who can recognize their own innate biases and prejudices and are willing to be transparent about them. Can a sensor be built to behave with the same integrity? Alternatively, can a sensor be built to warn you when it has reasons to believe the data it has collected may be flawed, unreliable or questionable?

Tony Zarola, general manager of Analog Devices, thinks it's imperative that we build sensors that way. After all, in the coming era of autonomous vehicles, we'll be relying on them to navigate our cars and our loved ones to safety. He calls the integrity-like characteristic in sensors "sensor robustness."

"We've been making sensors for a long time, so we understand how our sensors detect and measure information," he says. "We design and calibrate [the sensor] so that it can reject data like vibration from a gravel road, for example. That translates to sensor robustness. We understand what can impact this robustness. So we've made the sensor to be immune to the mitigating factors. And in times when the sensor is not confident in the data it has collected, it will let you know."

In dealing with edge device sensor data, engineers and data scientists grapple with not only the volume but also the quality of the data. Here, according to the observation of many industry insiders, all roads lead not to Rome but to machine learning (ML) and artificial intelligence (AI).

## Do You Trust your IMUs?

At present, carmakers have successfully put vehicles on the road that fall into what the Society of Automotive Engineers (SAE) describes as Level 2: Partial Automation. Many carmakers are also contemplating skipping Level 3: Conditional Automation. Instead, they may aim straight for Level 4: High Automation or Level 5: Full Automation. (For more, read the article "*Leveling Up in Autonomy*," page 12.)

"Level 3 presents an interesting challenge because, in some circumstances, the vehicle needs to hand the control back over to the driver. This is an area of uncertainty," explains Zarola. "The questions are: How much time does the system have before the human takes over? What does the system do while it waits for the human to take over? Remember, this period could be 10 to 15 seconds."

As Zarola sees it, while the autopilot or the advanced driver assistance system (ADAS) is waiting for the human driver to take over, the burden to keep the car navigating safely falls on the inertia measurement units (IMUs). "The IMUs have to be of a certain performance level so it can handle that period," he says.

Anticipating Level 4 and 5, Zarola and his colleagues plan to bolster their radar systems' resolution. The goal is to enable object detection. "We're also looking to reduce reaction time, in terms of objects coming at the vehicle from an orthogonal angle," he says. "Cameras may take many frames to determine what it sees before it can react."

While testing its large animal detection system, Volvo discovered the program didn't know how to deal with kangaroos ("Volvo admits its self-driving cars are confused by kangaroos," *The Guardian*, June 2017, theguardian.com).

A fully autonomous Level 5 vehicle, in Zarola's view, is still in the far future. "We still have some way to go in terms of data collection to improve sensor fusion and using AI to recognize objects," he says.

## Retrofitted IoT

For many manufacturers, replacing legacy machines with a new batch of costly connected devices is not practical. Therefore, the solution rests with retrofitting—placing sensors on old devices to begin gathering intelligence. This is a low-barrier entry to the Internet of Things (IoT) era.

"In the future, more and more manufacturing equipment providers will offer smart machines with built-in sensors and services, but it'll take time before these smart machines go into operation or reach the field. In the meantime, you'll have a mix of machines that need retrofitting, and machines that are already outfitted with sensors," says Julien Calviac, head of strategy for EXALEAD at Dassault Systèmes.

"In condition monitoring of motors, the package itself influences the translation of the data," Zarola points out. "Even the materials, the way you connect the sensor to the motor, and the adjacent machineries could corrupt the data."

But even in the era of IoT, the I (internet connectivity) is not always a given. "On a train going through a tunnel or a piece of equipment in a mine, you can't always be connected, so if you're logging data from a device like that, if the monitoring algorithm needs to connect to the network to operate, you might have to consider that in your choice of the edge," warns Seth DeLand, product marketing manager, data analytics, MathWorks

## Machine Learning's Dilemma

Collecting data from edge devices gives you a wealth of data—hourly temperatures and vibrations from a factory equipment or the daily wind loads a wind turbine is subjected to, for example—but not necessarily an easy path toward failure analysis or product design improvement.

The first hurdle is most likely the data quality. "The data from the devices isn't going to be as clean as the data engineers are used to getting from a physical test or a lab," says DeLand. "It might include, for example, a chunk of data resulting from someone bumping on a sensor. There might be missing time slices in the data because the equipment broke down. It often requires a significant amount of cleanup and preprocessing before you can use it."

Many firms catering to connected device makers propose AI-driven software and methods as the ideal way to tackle the vast amount of edge data, to find meaningful patterns and insights in it. But that too is a double-edged sword.

"The data you collect is usually not rich enough for AI to learn, not to mention deliver on users' expectations. For AI to learn enough and provide not just predictions but also prescriptions, you need more context information," says Calviac. "You need to have not only field data from the edge devices but also data from the engineering department (thresholds, rules, requirements), process information from manufacturing execution systems and simulation data."

For data analysis, Dassault Systèmes offers EXALEAD, originally a semantic-based enterprise search engine. The technology has evolved into an information intelligence engine, that is AI-powered, and capable of crawling, discovering and classifying all types of data, from text-based requirements and field reports to 3D engineering models, products data, bill of material (BOM) graphs and IoT, to support users with decision support to improve operations performance and accelerate innovation.

"With data streaming in from multiple sensors, you can't visualize it to make sense of it. So you might need ML to help you understand the patterns," says DeLand. "But ML is garbage in, garbage out. If the data you use to train and develop the model is flawed, then your resulting model is flawed."

In the best scenario, ML produces a code or model you can use with confidence. Here, too, is a catch: "You want to avoid the black box dilemma," cautions Calviac. "The AI will deliver you a model, but recommendations provided by that model may not be easy to understand or be trusted by experts and end-users."

## Sensing Oversteering

One successful example of using sensor data for safety and design improvement is recorded by BMW Groups in October 2018. To understand the complex factors that contribute to oversteering, and to develop a way to detect oversteering, BMW Group decided to equip a BMW M4 with sensors and drive it on a track, logging when the vehicle was in an oversteer situation. What resulted from the test was 200,000-plus data points in less than 45 minutes. ("Detect-


Analog Devices believes its robust sensors are an important part of the development of autonomous driving. *Image courtesy of Analog Devices.*

ing Oversteering in BMW Automobiles with Machine Learning;" mathworks.com).

Working in MATLAB, the BMW team developed a supervised machine learning model as a proof of concept. Even with little previous ML experience, they were able to complete a working electronic control unit prototype capable of detecting oversteering in just three weeks, as stated in the article.

The BMW team loaded the data collected with the Classification Learner app in Statistics and Machine Learning Toolbox to train machine learning models using a variety of classifiers, providing initial results that were between 75% and 80% accurate. After cleaning and reducing the raw data, the process was repeated and classifier accuracy improved significantly, to over 95%, according to the article. **DE**

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

**INFO ➜ Analog Devices:** Analog.com

➜ **MathWorks:** MathWorks.com

➜ **Dassault Systèmes:** 3DS.com

For more information on this topic, visit DigitalEngineering247.com

# Get Cracking with ANSYS Workbench 19.2

Walk through a fracture analysis using ANSYS Separating Morphing Adaptive Remeshing Technology.

**BY TONY ABBEY**

***Editor's Note:** Tony Abbey provides live e-Learning courses, finite element analysis (FEA) consulting and mentoring. Contact tony@fetraining.com for details, or visit his website at [fetraining.net](fetraining.net). This software walkthrough represents the author's independent assessment. However, in many cases he is indebted to the companies for supplying temporary licenses to allow the reviews to be carried out.*

I AM REVISITING ANSYS Workbench to carry out a series of Fracture Mechanics analyses (see *DE* February 2019 article; digitalengineering247.com/r/22182). I was particularly interested in the new ANSYS Separating Morphing Adaptive Re-meshing Technology (SMART). The acronym is a bit of a mouthful, but is an accurate description of the solver's capabilities. As the crack front moves forward, the mesh splits around it, and the surrounding zone is remeshed.

Fig. 1 shows the project opened and saved. A Static Structural analysis is dragged to the Project Schematic window and named as "Edge crack metric SMART."

The Engineering Data tab allows access to the material definition. I have accepted the default material, which is a generic Steel. I will start with a static analysis—an overload that creates a nonlinear fracture surface (i.e., a crack) in the model. The key material property is the Fracture Toughness, which is defined in a Fracture object, as we will see shortly.

The test model is an edge crack in a thick plate. The geometry was created externally and imported into SpaceClaim. The layout is shown in Fig. 2.

With the geometry in place, double-

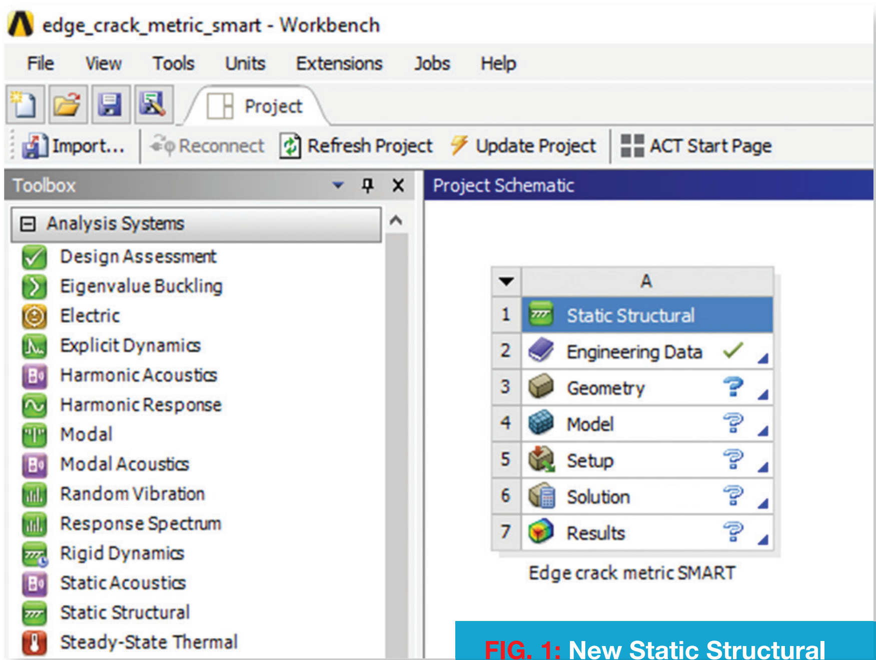


**FIG. 1: New Static Structural analysis in the Project Window.**

clicking on the Model tab in Fig. 1 launches ANSYS Mechanical. There are several tasks to perform here specific to the fracture mechanics analysis.

The SMART fatigue option requires a tetrahedral element mesh. The mesh size needs to be refined around the crack tip. I have used a sphere of influence method based around the geometric edge running through thickness.

I must select three named geometric regions to define the crack. These are the crack edge, the top surface of the crack and the bottom surface of the crack. Each of these regions is then associated with a node set for use in the analysis.

A local coordinate system is defined for the crack tip. The components indicate crack propagation direction (x) and crack opening direction (y).

The selected entities and coordinate system are shown in Fig. 3.

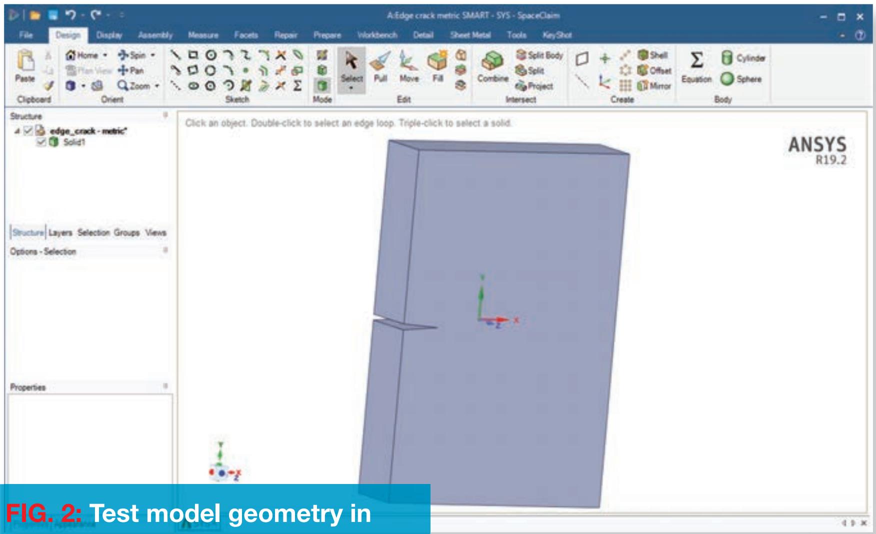


FIG. 2: Test model geometry in SpaceClaim.

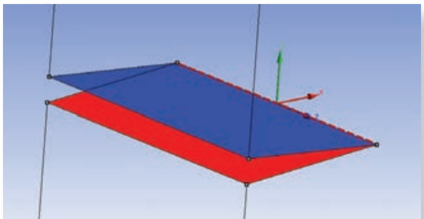

FIG. 3: Named surface, edge and coordinate system for crack.

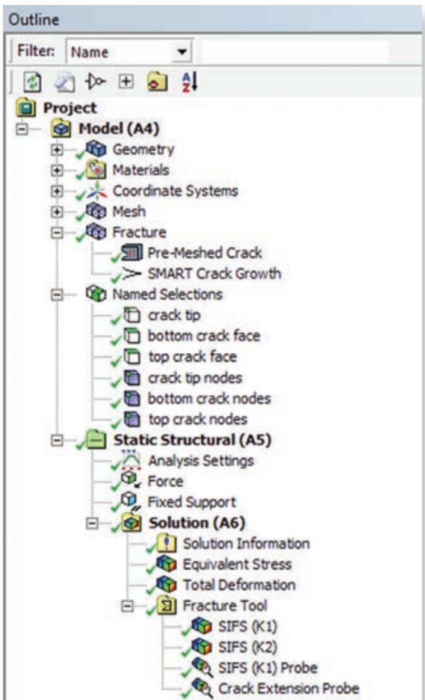


FIG. 4: The Analysis Tree showing fracture objects.

From the Command ribbon, the option for Fracture is chosen. Further options for introducing a crack are: Arbitrary Crack; Semi-Elliptical Crack and Pre-Meshed Crack.

The Pre-Meshed Crack option is selected. Fig. 4 shows the complete set of objects used to set up the Static Fracture analysis.

Within the Pre-Mesh Crack object, the Node sets created previously are allocated to the crack front, and the crack top and bottom faces. The crack coordinate system is referenced. The number of solution contours is set to 5. These are the "loops" through the mesh around the crack tip, which are used to evaluate the Stress Intensity Factor by integrating the crack tip region strain energy. The Fracture Mechanics approach avoids the stress singularities at the crack tip in the analysis.

In the Fatigue menu ribbon, three methods are available to model the crack front and its growth: Interface Delamination, Contact Debonding and SMART Crack Growth.

SMART Crack Growth is selected, and the menu is shown in Fig. 5.

The Pre-Meshed crack object is selected, the option to carry out a Static Fatigue analysis is chosen and the Critical Fracture Toughness is defined. The Stress Intensity Factor method is selected in this case. The crack will propagate when the calculated Stress Intensity Factor, $K$ exceeds the Fracture Toughness $K_c$. This calculation is done along the distributed crack front, and the distribution of Stress Intensity Factor will control the adapting crack front shape. The Failure Criteria can also be set to the J-Integral method.

Fig. 4 shows output requests and includes general stress and displacement contours as well as fatigue-specific probes. The main fracture mechanism in this model is the crack tensile opening Mode 1, which calculates $K_I$. The probe SIFS (K1) reports these values.

I have also included a probe for the in-plane shearing Mode 2, which calculates $K_{II}$ as SIFS (K2). These values are secondary for this configuration but may become important for a crack that changes direction significantly with a resulting shear stress environment. I have also included a crack extension probe to monitor the crack growth. Each of these probes will produce an XY plot.

I have constrained the bottom surface of the test piece and applied a vertical force of 1.5E5N. The initial crack length is 6.4 mm. A manual calculation gives a value for $K_I$ of 6.152E7 $\mathbf{Pa}\sqrt{\mathbf{m}}$. This is below the Critical $K_c$ of 1.5e8 $\mathbf{Pa}\sqrt{\mathbf{m}}$ input in Fig. 5. The component will not fracture under this loading. The main objective is to check the value and distribution of $K_I$.

## A Static Fracture Analysis

After launching the analysis, the distribution of $K_I$ along the crack front is shown in Fig. 6.

The manual calculation referenced is for an assumed infinitely deep plane strain section and is a one-dimensional (1D) approximation. The value matches the finite element analysis (FEA) distribution well. The edge effect can be seen in the 3D model.

There are five curves shown in Fig. 6. These represent the five contours requested in the Pre-Mesh Crack object. They are used to check for convergence of the $K_I$ value. The first curve is from a contour close to the crack tip; the other curves represent contours at increasing distances. The curves converge quickly, showing the mesh is adequate.

I then increased the load to 7E5N, which gives a $K_I$ of 3E8 $\mathbf{Pa}\sqrt{\mathbf{m}}$ for the initial crack length of 6.4 mm. This is greater than $K_c$ and results in a static fracture. Running the model with 40 Substeps results in a crack extension of 14.5 mm. The crack extends to just over 50% of the plate width. Fig. 7 shows the changing crack and mesh configuration. The maximum stress contours are adjusted at each step.

Fig. 8 shows the average $K_I$ as the crack progresses, together with the threshold $K_c$, shown as an orange dashed line. The location to sample along the crack front can be selected, and I have used the midpoint of the crack front.

No geometric nonlinearity allowed—so the crack length here is limited realistically unless we use a displacement control. The eccentricity created by the crack would result in very large bending stresses in the residual material, as the crack runs out, with a resulting complex failure mechanism. A crack extension limit can be defined to prevent an unrealistically long crack.

## A Fatigue Fracture Analysis

The fracture type in the SMART Crack Growth object is now set to Fatigue—an investigation of the Fracture Mechanics response under a cycling load. This requires additional material data definitions for the Paris Law. The Paris Law is defined by:

$$\frac{da}{dN} = C\Delta K_I^{m^*}$$

where:

$\frac{da}{dN}$ is the rate of crack growth per cycle;

$\Delta K_I$ is the Stress Intensity Factor range (based on maximum stress and minimum stress);

$C$ is the Paris Law coefficient; and

$m^*$ is the Paris Law exponent.

The additional data required are the coefficient and exponent. The units of the coefficient material data are tricky as they embody the exponent m in the conversion. (I will be writing about non-intuitive units in a future article!)

The material data I used was:

$C$ = 1.9e-29 : units are m/(MN m^-3/2)^m*

$m^*$= 2.8 : dimensionless

The Stress Ratio is used to define the ratio of minimum stress to maximum stress. This gives the stress

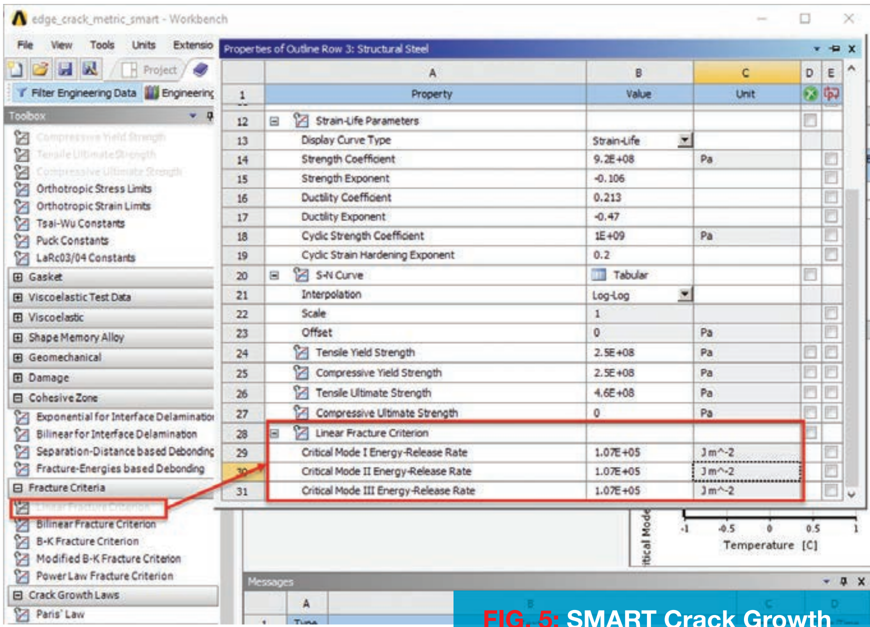


FIG. 5: SMART Crack Growth menu.

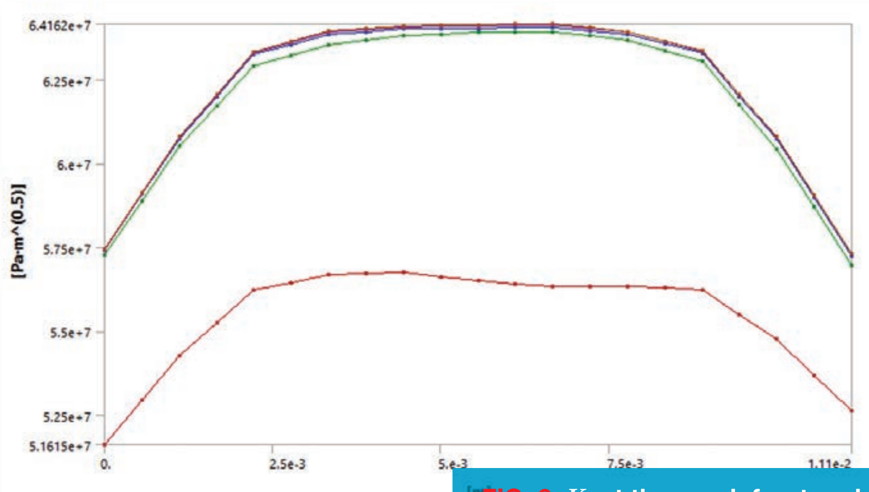


FIG. 6: $K_I$ at the crack front under initial loading.

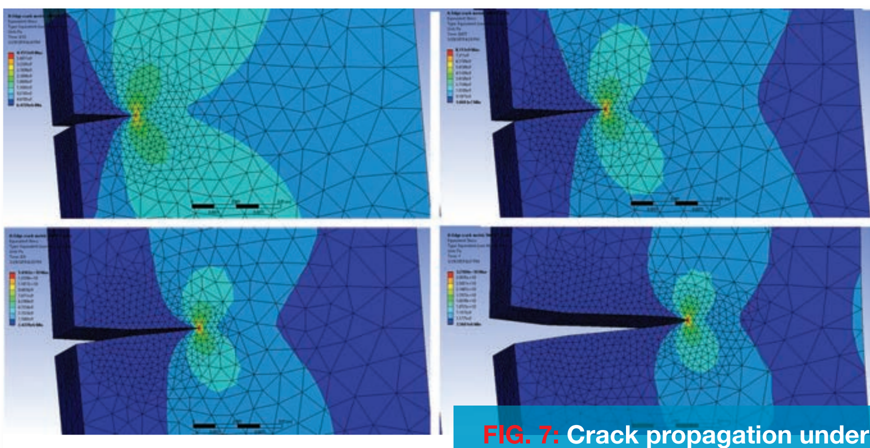

FIG. 7: Crack propagation under static loading.

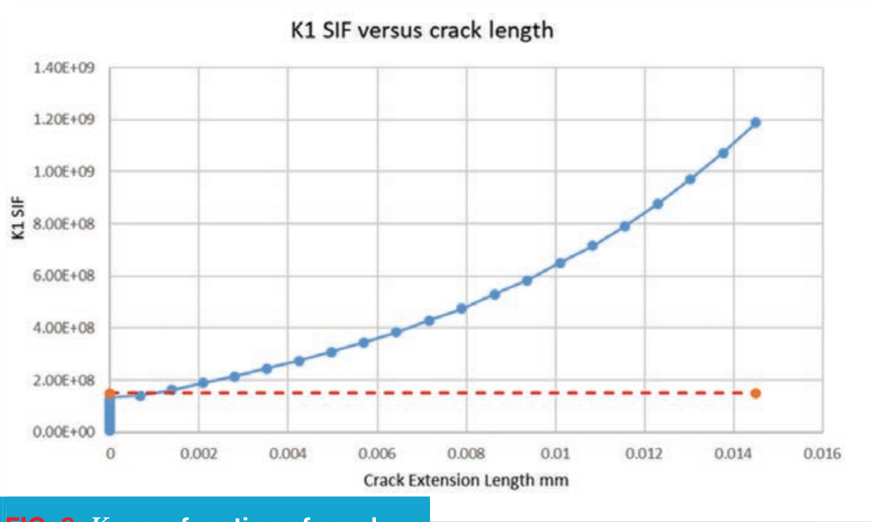


**FIG. 8:** $K_I$ **as a function of crack length extension.**

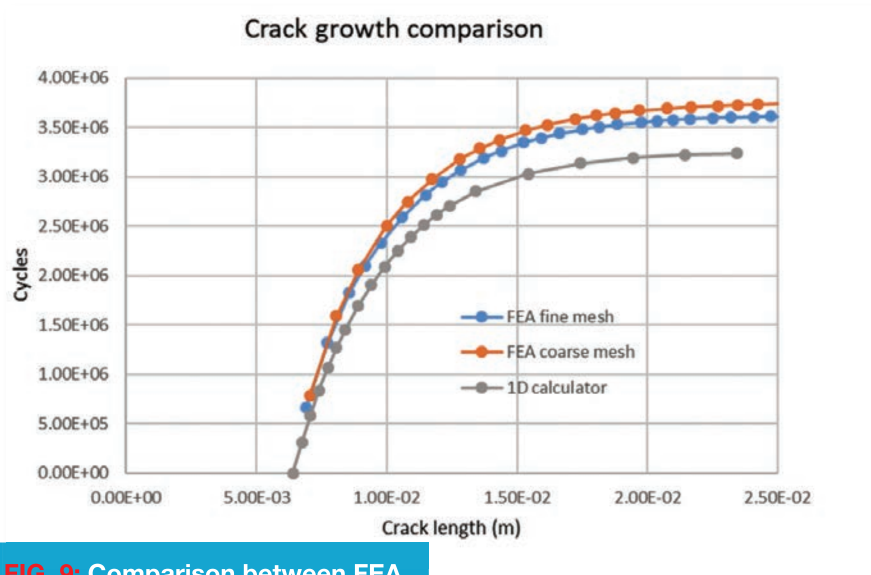


**FIG. 9: Comparison between FEA coarse and fine mesh results and 1D solution.**

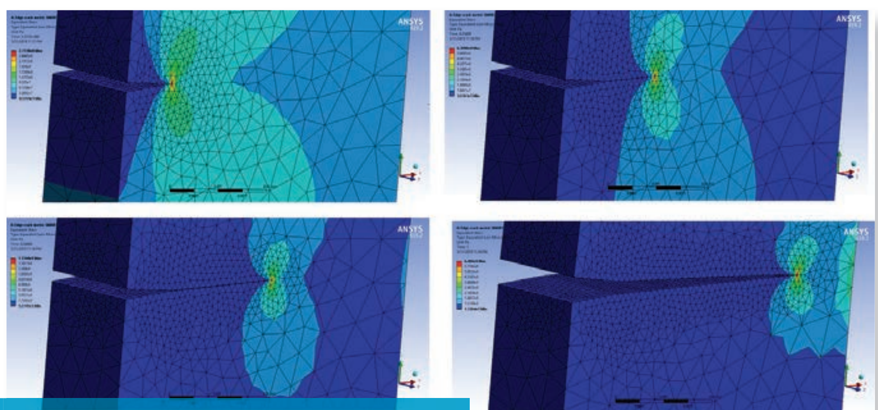

**FIG. 10: Crack extension through life.**

range and hence the Stress Intensity factor range. In my case, the stress is cycling from zero to maximum, so the ratio is 0.0. If the stress was fully reversed, the ratio would be -1.0.

The load is dropped to a much lower level of 27.0 KN, appropriate for a continuous cyclic operational loading.

A data probe is added to report the number of cycles for each crack increment.

A solution for an approximate 1D solution can be found using this expression:

$$Nf = \frac{1}{C\left(\Delta K_I\sqrt{\pi}\right)^m}\left(\frac{1}{m/2-1}\right)\left[\frac{1}{a_0^{m/2-1}} - \frac{1}{a_f^{m/2-1}}\right]$$

$a_0$ is the initial crack length and
$a_f$ is the final crack length.

The catch is that the Stress Intensity Factor range, $\Delta K_I$ is a function of crack length, so the equation has to be evaluated numerically. I have an Excel spreadsheet to perform this 1D approximation.

After I run the fatigue analysis, the probes are used to recover the Number of Cycles vs. Crack Length, as in Fig. 9.

Two ANSYS runs are carried out: a relatively coarse mesh and a finer mesh. The local element size is reduced from 0.8 mm to 0.65 mm. There is clear evidence of convergence with the life to create a 25 mm crack reducing from 3.74 E6 cycles to 3.62 E6 cycles. The 1D model provides a useful comparison with a life to 25 mm of 3.24 E6 cycles.

The convergence accuracy is based on both mesh size and initial crack step length. Both are controlled in ANSYS by the mesh size. So, finding a sufficiently fine mesh is important.

The crack extension through life is shown in Fig. 10. The stress contours are adjusted to maximum values at each step.

A hole is now inserted in the SpaceClaim model. The project is updated and automatically remeshed. No other modification is required, and the analysis is relaunched. The result of the modification is shown in Fig. 11.

The crack is now attracted to the hole and joins it on the far side from the crack origin. The crack is then arrested and there is no further extension. The crack is arrested at around 8.631 E5 cycles and the structure is damage tolerant with respect to this particular initial crack and loading.

The SpaceClaim geometry is modified by dragging the hole further away from the crack axis. The model is updated and again automatically remeshed. The results of this analysis are shown in Fig. 12.

The crack is influenced by the hole but bypasses it. Interestingly, the crack growth rate speeds up compared to a plate without a hole. The number of cycles to reach the critical crack length has dropped to 1.09 E6 cycles. This is around one-third of the total for the plate without a hole. The relationship between the hole and the crack is clearly important. The hole can arrest the crack—or speed it up!

A more arbitrary shaped hole was investigated, positioned at the same point, but elongated slightly in the vertical axis. The results of this analysis are shown in Fig. 13.

The hole attracts the crack but is not a strong enough influence to arrest it. It also acts to speed up the crack propagation further with 1.2 E5 cycles to the critical length.

Finally, a sharp notch in the hole edge was modeled to see if the crack would be attracted. This is shown in Fig. 14.

The sharp notch does attract and arrest the crack. It now takes 6.76 E5 cycles to reach this point. The notch is intercepted partway along its length. This is shown more clearly in the displacement plot, which is inset in the last frame of Fig. 13. Experimenting with the notch shows there is a critical length to attract the crack to an arrested state. Below that length the notch acts to accelerate the crack.

The workflow to set up the crack and define the fracture parameters is straightforward. The direct interface with SpaceClaim geometry allows for rapid "what-if" studies. This is a versatile tool and I have only shown one crack type.

The Arbitrary Crack and Semi-Elliptical Crack look useful in creating cracks in more complex geometry. The other fracture solution methods, Interface Delamination and Contact Debonding, provide solutions for pre-defined crack paths, such as along bond lines. **DE**

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**Tony Abbey** *has created a Fatigue and Fracture Mechanics e-learning class that is presented in partnership with NAFEMS. Check it out:* *https://goo.gl/oS4TBd*.

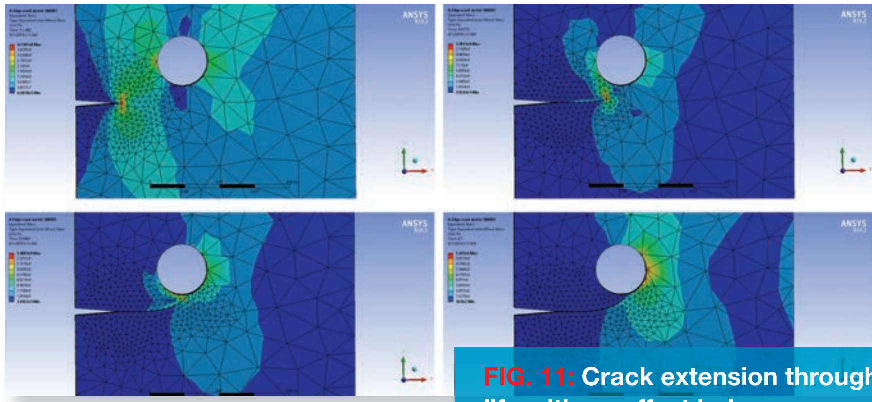


**FIG. 11: Crack extension through life with an offset hole.**

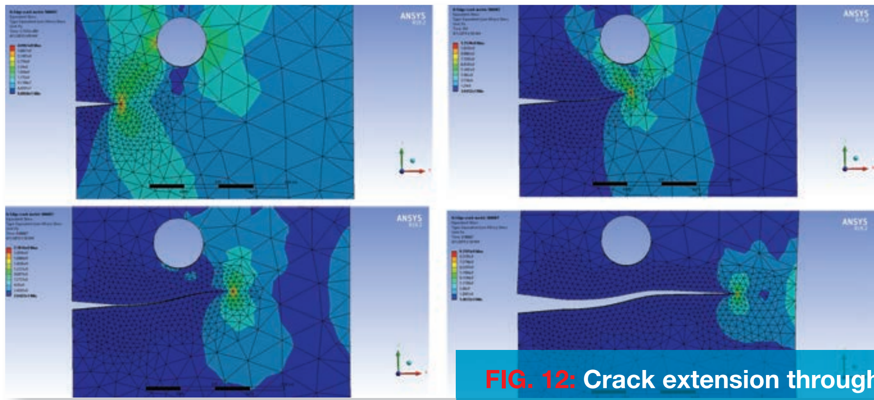


**FIG. 12: Crack extension through life with a further offset hole.**

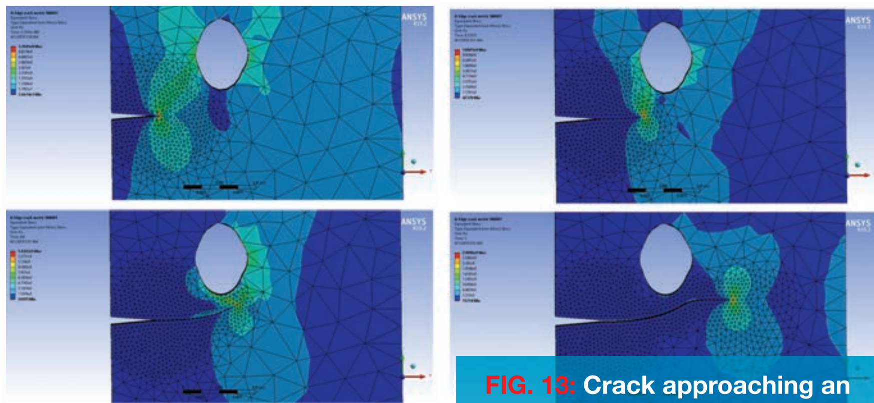


**FIG. 13: Crack approaching an elongated hole.**

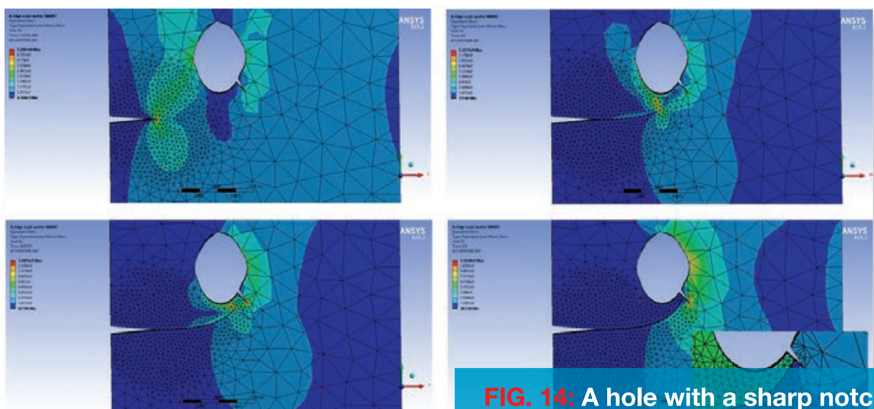


**FIG. 14: A hole with a sharp notch showing crack growth.**

# Powerful, Lightweight and VR-Ready

The MSI WS65 8SK mobile workstation delivers great performance.

BY DAVID COHN

IT HAS BEEN MORE THAN A YEAR since we last reviewed a system from Micro-Star International (MSI). Unlike the large desktop replacement system the Taiwan-based company sent us last time around (*DE*, November 2017; digitalengineering247.com/r/17141), the WS65 8SK system we recently received is a thin, lightweight system suited for an engineer or designer who wants to travel light.

The WS65 8SK measures 14.08x9.75x0.69-in. (WxDxH) and weighs 4 lbs. The 180-watt power supply (6.0x2.75x0.87-in.) adds an additional 1.25 lbs. It features an attractive brushed black aluminum case with bronze accents on the side air grilles and around the lid.

Unlike many other original equipment manufacturers, MSI does not offer custom configurations. The company sells two preconfigured systems based on specific component combinations. For example, the computer we received—the WS65476—is based on a 2.9GHz Intel Core i9-8950HK CPU and a CM246 chipset.

MSI also sells the WS65431, based on an 2.2GHz Intel Core i7-8750H CPU and a HM370 chipset. Other than the CPU and chipset, the two systems are identical. Prices often vary because MSI only sells through authorized resellers who can set their own prices. We found the less powerful WS65431 for $2,699 through Amazon, where we also found the WS65476 for $4,249 (whereas CDW sells the same WS65476 for $319 more).

The processors in both models are six-core Coffee Lake CPUs and include Intel UHD 630 graphics. The Core i9-8950HK in our evaluation unit has a maximum turbo speed of 4.8GHz, a 12MB cache and a 45-watt Thermal Design Power rating. Both systems also include an NVIDIA Quadro P3200 graphics card. This discrete graphics processing unit (GPU) includes 6GB of dedicated GDDR5 graphics memory and 1792 CUDA cores and is virtual reality (VR) ready.

Both systems also come with 32GB of RAM, installed as two 16GB dual in-line memory modules and both have a 512GB M.2 PCIe non-volatile memory express solid-state drive.


**The MSI WS 65 8SK is a powerful 15.6-in. mobile workstation that features good design, light weight and great performance.** ***Image courtesy of MSI.***

## Nice Port Assortment

Lifting the lid reveals the 15.6-in. display and a backlit keyboard with 80 keys. An oval-shaped power button is centered above the keyboard, with an adjacent LED that glows white when the system is powered on and using the Intel graphics, or amber when the discrete NVIDIA GPU is in use.

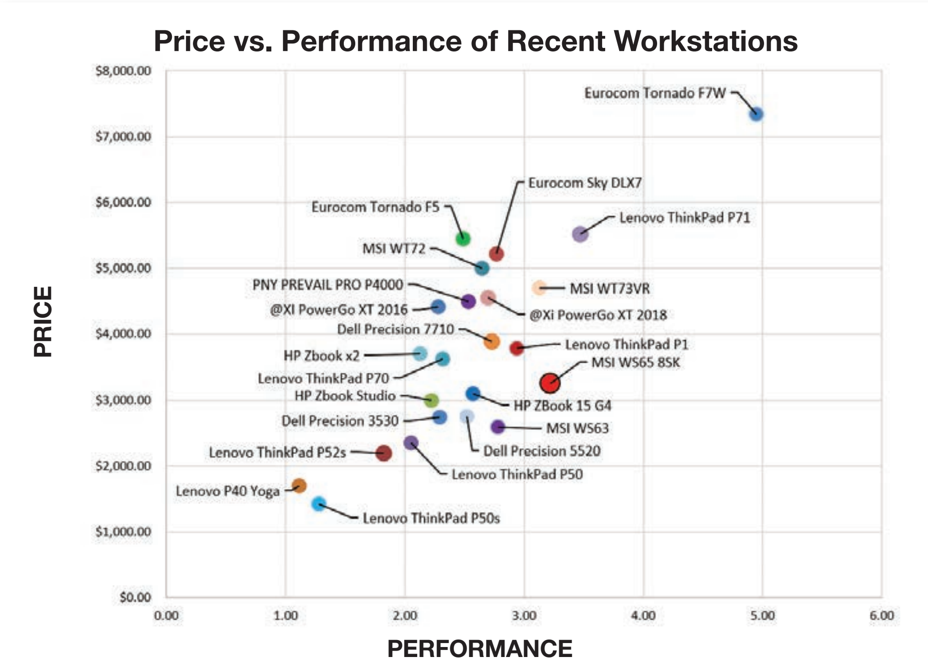
A 720p webcam, centered above the display, is activated by pressing the F6 key. An LED to the right of the camera blinks when the webcam is active. There is also a small LED on the Caps Lock key. A 4x2.75-in. touchpad with multi-touch capabilities is centered below the spacebar. Although the keyboard lacks dedicated buttons, you can click in the lower-right corner to access right-click shortcut menus. A fingerprint reader is in the upper-left corner of the touchpad.

The right side of the case provides a USB 3.1 port, a Thunderbolt 3 port, a mini-DisplayPort, an HDMI port and the connection for the AC adapter. The left side of the case includes two additional UBS 3.1 ports, an RJ-45 network port, headphone and microphone jacks, and a Kensington Lock slot.

MSI includes a TrueColor app that lets you select various

| Mobile Workstations Compared | **MSI WS65 8SK** 15.6-inch 2.90GHz Intel Core i9-8950HJ 6-core CPU, NVIDIA Quadro P3200, 32GB RAM, 512GB NVMe PCIe SSD | **Eurocom Tornado F7W** 17.3-inch 3.60GHz Intel Core i9-9900K 8-core CPU, NVIDIA Quadro P5200, 64GB RAM, 500GB NVMe PCIe SSD, 2TB HD | **Lenovo ThinkPad P1** 15.6-inch mobile 2.70GHz Intel Xeon E-2176M 6-core CPU, NVIDIA Quadro P2000, 32GB RAM, 2TB NVMe PCIe SSD | **Dell Precision 3530** 15.6-inch 2.7GHz Intel Xeon E-2176M 6-core CPU, NVIDIA Quadro P600, 32GB RAM, 512GB NVMe PCIe SSD | **@Xi PowerGo XT 2018** 17.3-inch 4.0GHz Intel Core i7-8086K 6-core CPU, NVIDIA Quadro P4200, 32GB RAM, 500GB NVMe PCIe SSD | **Lenovo ThinkPad P52s** 15.6-inch 1.9GHz Intel Core i7-8650U quad-core CPU, NVIDIA Quadro P500, 16GB RAM, 1TB NVMe PCIe SSD |
|---|---|---|---|---|---|---|
| Price as tested | $3,249 | $7,346 | $3,788 | $2,738 | $4,558 | $2,196 |
| Date tested | 12/12/18 | 12/12/18 | 10/24/18 | 8/28/18 | 8/7/18 | 6/12/18 |
| Operating System | Windows 10 | Windows 10 | Windows 10 | Windows 10 | Windows 10 | Windows 10 |
| SPECviewperf 12 (higher is better) | | | | | | |
| catia-04 | 115.38 | 183.15 | 64.58 | 38.67 | 165.95 | 28.64 |
| creo-01 | 97.82 | 151.79 | 52.95 | 42.99 | 138.65 | 33.26 |
| energy-01 | 12.46 | 20.03 | 6.50 | 3.12 | 14.87 | 0.55 |
| maya-04 | 91.69 | 139.69 | 41.74 | 38.42 | 128.84 | 20.96 |
| medical-01 | 60.10 | 94.74 | 27.81 | 12.61 | 63.65 | 9.41 |
| showcase-01 | 61.83 | 80.91 | 29.91 | 19.70 | 73.41 | 12.55 |
| snx-02 | 137.83 | 214.49 | 61.50 | 37.25 | 172.95 | 43.91 |
| sw-03 | 123.80 | 201.96 | 76.73 | 70.59 | 181.61 | 50.01 |
| SPECapc SOLIDWORKS 2015 (higher is better) | | | | | | |
| Graphics Composite | 4.67 | 5.84 | 2.58 | 4.77 | 5.32 | 1.94 |
| Shaded Graphics Sub-Composite | 2.98 | 4.03 | 1.33 | 3.17 | 3.48 | 1.17 |
| Shaded w/Edges Graphics Sub-Composite | 3.88 | 4.99 | 1.91 | 4.06 | 4.38 | 1.64 |
| Shaded using RealView Sub-Composite | 3.37 | 4.49 | 1.76 | 3.59 | 3.87 | 1.48 |
| Shaded w/Edges using RealView Sub-Composite | 3.89 | 5.08 | 2.29 | 4.07 | 4.36 | 1.98 |
| Shaded using RealView and Shadows Sub-Composite | 3.87 | 5.11 | 2.05 | 4.10 | 4.46 | 1.69 |
| Shaded with Edges using RealView and Shadows Graphics Sub-Composite | 4.11 | 5.28 | 2.45 | 4.26 | 4.61 | 2.00 |
| Shaded using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite | 12.97 | 13.83 | 6.35 | 11.20 | 14.75 | 3.01 |
| Shaded with Edges using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite | 12.14 | 13.68 | 6.87 | 11.01 | 13.51 | 3.54 |
| Wireframe Graphics Sub-Composite | 3.69 | 4.45 | 3.06 | 3.85 | 4.15 | 2.43 |
| CPU Composite | 4.58 | 3.86 | 2.85 | 4.55 | 5.40 | 1.72 |
| SPECwpc v2.0 (higher is better) | | | | | | |
| Media and Entertainment | 3.22 | 5.15 | 3.13 | 2.23 | 4.14 | 1.71 |
| Product Development | 3.22 | 4.95 | 2.94 | 2.29 | 2.70 | 1.82 |
| Life Sciences | 3.60 | 6.19 | 3.66 | 2.26 | 4.40 | 1.83 |
| Financial Services | 4.11 | 6.16 | 4.20 | 3.34 | 5.37 | 1.91 |
| Energy | 3.56 | 5.62 | 5.02 | 2.28 | 4.08 | 1.42 |
| General Operations | 1.38 | 1.96 | 1.67 | 1.30 | 1.55 | 1.20 |
| Time | | | | | | |
| Autodesk Render Test (in seconds, (lower is better) | 35.50 | 34.10 | 46.40 | 63.10 | 29.30 | 89.70 |
| Battery Life (in hours:minutes, higher is better) | 9:01 | 4:40 | 7:08 | 9:26 | 3:56 | 5:33 |

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




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

display profiles and its Dragon Center application that lets you monitor system components, tune performance and access the user manual and help desk.

Like most modern systems, the battery is not removable, and the manual does not address any user-serviceable components. During our tests, the MSI WS65 8SK remained cool and relatively quiet, although the fan noise reached 55dB during some of our tests. The four-cell 82Whr Li-ion battery kept the system running for 9 hours on our battery run-down test.

## Great Performance

The MSI WS65 8SK performed quite well on all our benchmark tests. Thanks to its high-end Pascal-based mobile NVIDIA GPU, it turned in great results on the SPECviewperf test of graphics performance, earning very high scores for a 15.6-in. mobile workstation.

On the SPECapc SolidWorks benchmark, the MSI WS65 8SK also did very well, with results typical for a high-end mobile system. On the demanding SPECwpc benchmark, the MSI system also turned in results that led the pack of recent 15.6-in. systems. And on our own AutoCAD rendering test, the 35.5-second average rendering time was the fastest we've ever recorded for a thin, lightweight mobile workstation.

MSI preloads Windows 10 Professional 64-bit and backs the system with a three-year limited warranty that includes a one-year global warranty. MSI mobile workstations are independent software vendor-certified for major CAD/CAM software from Autodesk, Siemens and SolidWorks.

At the end of the day, the MSI WS65 8SK is priced well—though shop around to get the best pricing—and delivers great performance. Our conclusion: this is a great, thin, lightweight, VR-capable system that should suit any engineer or designer who needs a powerful mobile workstation but wants to travel light. DE

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**INFO → Micro-Star International:** msi.com

***MSI WS65 8SK***

- **Price:** $3,249 as tested ($2,699 base price)
- **Size:** 14.08x9.75x0.69-in. (WxHxD) notebook
- **Weight:** 4.0 lbs. plus 1.25-lb. power supply
- **Weight:** Six-core 2.9GHz Intel Core i9-8950HK w/12MB Smart Cache
- **Memory:** 32GB DDR4 at 2600MHz
- **Memory:** NVIDIA Quadro P3200 w/6GB GDDR5 memory
- **LCD:** 15.6-in. FHD (1920x1080) IPS
- **Hard Disk:** 512GB M.2 NVMe
- **Audio:** Built-in speakers, two audio jacks (microphone, headphone), built-in microphone
- **Network:** Intel 9560 Jefferson Peak (2x2 802.11 ac) plus Bluetooth 5.0
- **Other:** Three USB 3.1, one Thunderbolt 3 (Type-C), HDMI, mini DisplayPort, RJ-45 LAN, 720p webcam
- **Keyboard:** Integrated 80-key backlit keyboard
- **Pointing device:** Integrated touchpad with fingerprint reader

AD INDEX

# EDITOR'S PICKS

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

## Design Visualization with Asset Management

Chaos Group V-Ray Next for Rhino 3D offers a design visualization workflow.

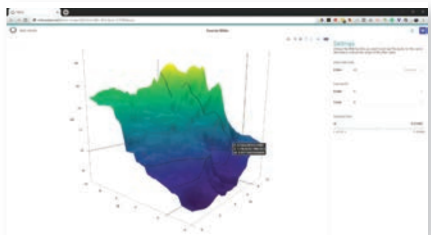
With Chaos Group's next-generation rendering engine, V-Ray Next for Rhino, no longer is rendering a Rhino model in V-Ray a disconnected event from the product workflow. It is now the centerpiece of a design visualization workflow.

Chaos Group says a rewrite of V-Ray's materials engine boosts rendering speed by up to 50%. There's also RhinoScript and Python support for additional automation and customization.

**MORE →** digitalengineering247.com/r/22396

## Machine Learning Support for Simulation

Autonomous optimization helps simplify complex engineering processes.



ESTECO VOLTA is a platform for multidisciplinary business process automation and simulation data management. It simplifies processing and (re)using engineering knowledge generated by simulation. ESTECO calls it "Optimization Driven Design" because it runs all the time in the background, autonomously looking for patterns and best results within simulation data. It's sort of a Roomba for simulation data, one that runs on cloud services, HPC clusters or single workstations.

**MORE →** digitalengineering247.com/r/22370

## Siemens' New Alliance Offers HPC Performance

Rescale SaaS delivery provides compute resources on demand.

Simcenter users can now connect with global resources 24/7/365 for their largest and most complex simulation jobs. Rescale says it aggressively upgrades the network regularly, taking advantage of new hardware architectures as they become available.

You can work entirely in the cloud or only send up specific tasks. Both graphical-user-interface-centric processes and multi-node batch execution solves are available.

**MORE →** digitalengineering247.com/r/22346

## Powerful Ray Tracing GPU for Workstations

NVIDIA Quadro RTX 8000 brings AI features and advanced shading to workflows.


The big brother of NVIDIA's family of Turing architecture-based graphics processing units can handle more complex modeling, photorealistic rendering and deep neural network tasks than you thought was possible in a workstation.

NVIDIA says Turing accelerates real-time ray tracing operations by 25x over the previous Pascal generation. Also, support for NVLink, effectively merges two physical RTX 8000s into a single logical entity.

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# Next-Gen Engineers

Student Design Competition Profile: Engineering Innovation for Society

## Competition Embodies Spirit of "the New Polytechnic"

**BY JIM ROMEO**

THE DEPARTMENT OF Mechanical, Aerospace and Nuclear Engineering (MANE) at Rensselaer Polytechnic Institute (RPI) hosts a student design competition: the Engineering Innovation for Society competition. The group is gearing up for the second year of competition and expects to turn it into an annual event.

RPI says it's a "way to give students the opportunity to explore how engineering is used to develop creative solutions to real-world problems." It provides an opportunity for students to adopt the entrepreneurial and collaborative spirit of what they call: "The New Polytechnic," or the driving model for teaching, learning and research at Rensselaer.

We spoke to Dr. John Tichy, professor, Mechanical Aerospace and Nuclear Engineering at RPI to learn more about this competition.

***Digital Engineering:*** Can you provide an overview of the Engineering Innovation for Society competition?

**Dr. John Tichy:** The Engineering Innovation for Society competition challenges undergraduate students from top engineering schools across the Northeast to design new devices to help improve the lives of those with disabilities. [It's] a goal that also fits within Rensselaer's mission to change the world.

The competition is a partnership with the Center for Disability Services. Eight teams of four students each compete. The first competition was last year. The plan is to hold the second [competition] next year.

There are a lot of hacking competitions, and there are a lot of intercollegiate competitions out there that have attracted attention. We wanted to find one for us in a niche in which we think we excel and that could grow into something bigger.

**Students collaboratively design devices to improve the lives of people with disabilities. *Image courtesy of RPI.***

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

**Tichy:** The Center for Disability Services provides the real-world challenges for the students to tackle. Most of what they do is one-of-a-kind in nature. For the most part, these are problems that impact the people they work with. Each problem was kind of new and unique in itself, so students would come up with interesting solutions.

***DE:*** Can you provide some examples of what the event has produced or what you expect it to produce?

**Tichy:** The first thing the students had to do to come up with a good solution was to see the world through the client's eyes. That was really interesting. I think a lot of them walked away from it feeling enriched from that alone.

The teams came up with a number of solutions, like a device to get people from a wheelchair into a vehicle without being exposed to inclement weather; a writing instrument for people with Parkinson's; a hand splint to help someone with cerebral palsy open their hand; and a special chair for individuals with autism.

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

**Tichy:** One thing we've talked about, but haven't done yet, is take a winning design or two and go with it and see what it would take to make a true beta device and then make such a device with an eye to patent it and develop a viable product.

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

**Tichy:** This experience gave students the opportunity to learn how to work as a team; how to think on their feet; how to design on the fly; and how to use available tools, such as design software, 3D printing and standard machine shop [workflows]. It also allowed students to appreciate just how complicated design can be, especially real-world mechanical design. DE

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**INFO →** mane.rpi.edu