ANSYS

Excellence in Engineering Simulation

# ADVANTAGE

ISSUE 1 | 2018

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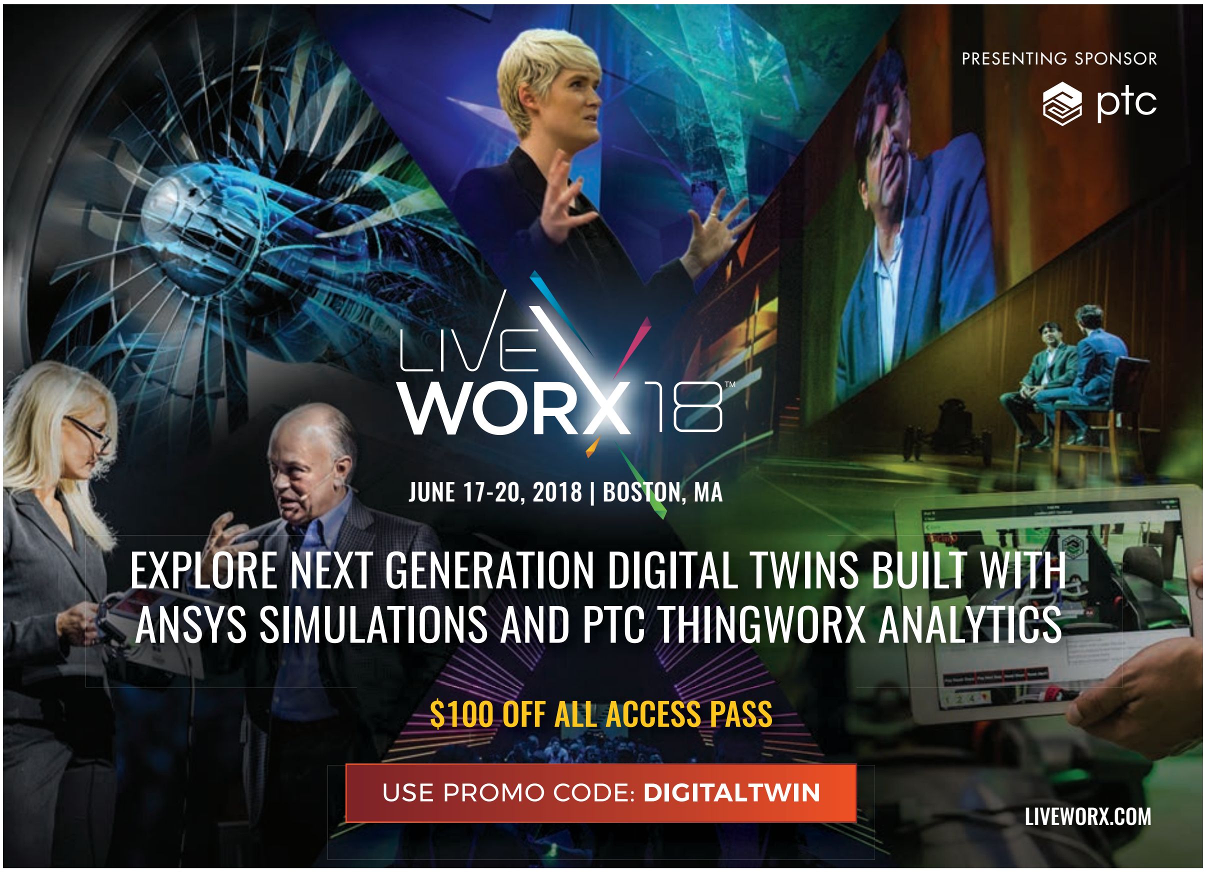
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# THE FUTURE IS SELF-DRIVEN

Autonomous vehicles are poised to redefine the global automotive and aerospace industries, among others. But designing these complex products for the required level of safety and reliability represents an engineering challenge without precedence.

By **Sandeep Sovani**,
Director for the Global Automotive Industry, ANSYS

Who doesn't get excited about the prospect of self-driving cars, aircraft and robotic vehicles? Once the stuff of science fiction movies and Saturday morning cartoons, autonomous vehicles are already becoming a reality — and will soon become commonplace.

Experts believe that the emergence of safe autonomous driving technology will completely reinvent the global automotive industry, replacing millions of privately owned cars with fleets of robo-taxis, similar to today's Uber and Lyft — but completely electric and self-driving.

While 2020 is the generally agreed-upon target for the first commercial release of autonomous cars, technology experts at RethinkX recently predicted that by 2030 — just 10 years later — a full 95 percent of U.S. passenger miles will be served by autonomous electric vehicles owned by companies providing Transportation as a Service (TaaS).[1]

Similarly, unmanned aerial vehicles, or UAVs, are expected to revolutionize the shipping industry, as Amazon, UPS, Domino's Pizza and other businesses aggressively invest in drone delivery capabilities.[2] A recent report from Interact Analysis estimates that there will be a six-fold increase in drone shipments by 2022 to meet this demand, resulting in industry revenues that will grow from $1.3 billion in 2016 to $15 billion in 2022.[3] Amazon has stated an ambitious goal: to eventually drone-deliver packages to consumers within 30 minutes of order placement.[4]

While these are exciting predictions, the world's engineers are tasked with the real, hands-on work of making this vision a reality in just a few short years. The design challenges associated with autonomous vehicles are unparalleled in the history of the transportation industry — and the bar for safety and reliability has never been set higher.

For example, consider the problem of weather conditions. How can self-driving cars sense highway lanes, other vehicles and pedestrians when thick fog or snow obscures their "vision" — i.e., their cameras, radar and lidar systems? How can drones sense and respond to the unexpected wind shifts that are typical of urban landscapes as they attempt to make deliveries?

Before they can be successfully launched onto real-world highways and into actual skies, autonomous vehicles must be exhaustively tested and certified for safe operation. But how can this rigorous testing take place for such complex products, while still meeting ambitious deadlines — and delivering a healthy profit margin?

The answer is engineering simulation. To capture the market opportunity — and with human lives at stake — only simulation combines a high degree of speed and cost-effectiveness with a high degree of product confidence. Multiphysics software from ANSYS enables companies to replace years of physical testing with simulations that replicate every aspect of autonomous vehicle performance under thousands of operating scenarios — all in a risk-free virtual environment.

As just one example, simulation allows product developers to view what sensors can actually "see" under a variety of real-world weather conditions — instead of waiting months or years to conduct physical testing under every possible weather scenario.

By developing and testing critical components such as software, electronics and sensors in a risk-free virtual world, ANSYS customers are among the leaders in the global drive toward vehicle autonomy. This issue of *ANSYS Advantage* highlights some of the advanced applications for simulation that are making the dream of autonomous vehicles a reality.

While it will be a few more years until our roads and skies are filled with self-driving cars and autonomous aircraft, these companies are shaping the future with their important product development work. Whatever your industry or product focus, we hope you will be inspired by the high-impact simulations they are performing to solve the most challenging problems related to vehicle autonomy.

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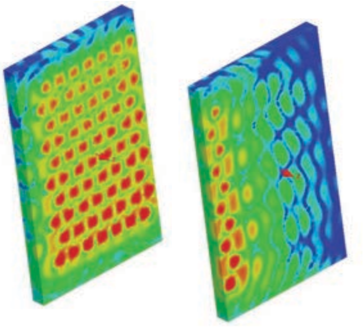

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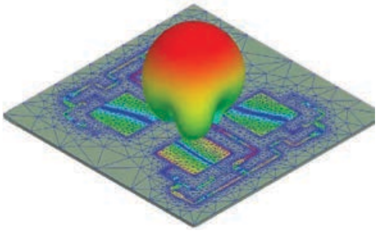


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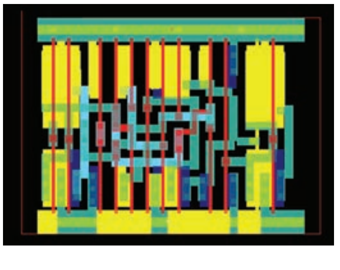


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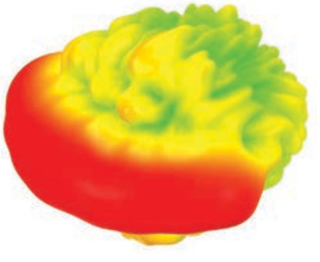


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*The race is on to achieve full autonomy within the next few years, which means overcoming a host of advanced engineering challenges. This issue of* ANSYS Advantage *demonstrates how simulation is critical in the drive toward full autonomy.*

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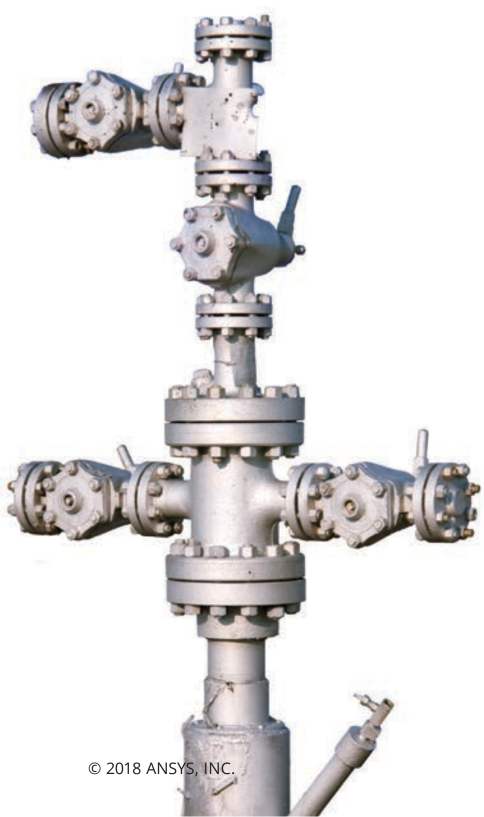


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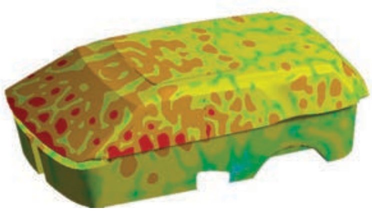


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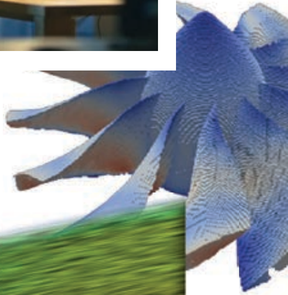
If you've ever seen a rocket launch, flown on an airplane, driven a car, used a computer, touched a mobile device, crossed a bridge, or put on wearable technology, chances are you've used a product where ANSYS software played a critical role in its creation.

ANSYS is the global leader in engineering simulation. We help the world's most innovative companies deliver radically better products to their customers. By offering the best and broadest portfolio of engineering simulation software, we help them solve the most complex design challenges and engineer products limited only by imagination.

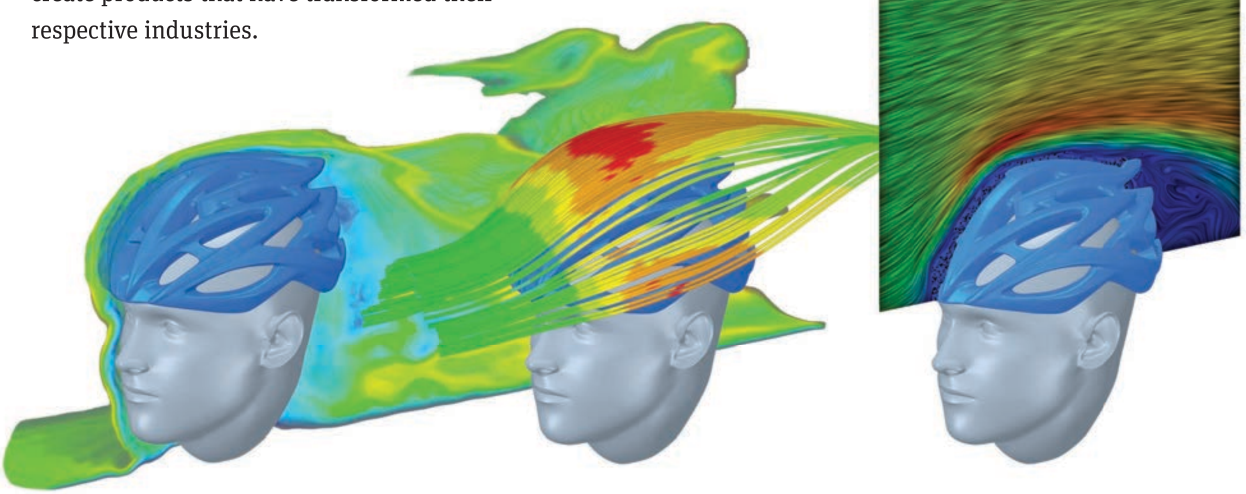
# Simulation Redefined

By **Mark Hindsbo,** Vice President and General Manager, ANSYS

**For the products of tomorrow to become a reality, engineering simulation must change. It will evolve to be the tool for every engineer, for every product, across the entire lifecycle. Without this evolution, we will not be able to fully capitalize on the opportunities created by Industry 4.0. Those who do less will be out-innovated.**



For nearly half a century, ANSYS has been instrumental in helping customers drive innovation with engineering simulation, while also reducing costs and product development time. From cars, planes and trains to consumer electronics, industrial machinery and healthcare solutions, ANSYS software has helped create products that have transformed their respective industries.

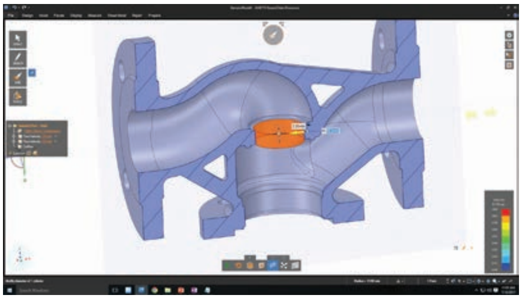


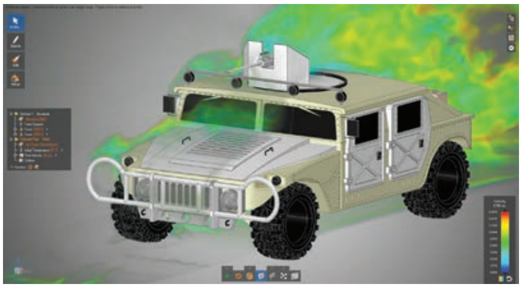

While we are amazed by our customers' achievements, we believe they represent only the beginning of the incredible value simulation can generate. Today, simulation is entering a new era, characterized by three fundamental changes:

- Simulation used to be a scarce resource applied in the design of only the most complex industrial products, but now is becoming integral to the design of every product.
- Product simulation examined single attributes: one physics, one component, one design. Now we explore a plethora of designs at the system level with interactions across multiple physical and digital domains.
- Perhaps most exciting, simulation is being leveraged not just for design validation, but from early ideation through manufacturing, operations and maintenance.

In short, engineering simulation is becoming more pervasive in its ability to positively impact product innovation and performance, drive top-line growth and deliver end-user benefits.

Because these trends are reshaping how ANSYS develops its engineering simulation software — as well as how customers worldwide, in every industry, leverage our solutions — it is worth considering each of these changes in more detail.





## A SIMPLE PRODUCT? NO SUCH THING

When engineering simulation debuted in 1970, it represented a novel capability — but one that required highly skilled engineering specialists to set up, as well as computing resources only available to the very largest organizations. As a result, it was almost exclusively applied to the most complex and costly engineered products, such as industrial machinery, cars and aircraft.

**Pervasive Simulation for a Digital World**
ansys.com/pervasive-world

> **"The *digital revolution* is happening in every *industry* and for every *product*."**

However, in 2018, there is no such thing as a simple product. Today, every design is being pushed to the limit to take advantage of composite materials, additive manufacturing and the high level of connectivity and automation enabled by Industry 4.0. The result is a new generation of smart, durable and sustainable products.

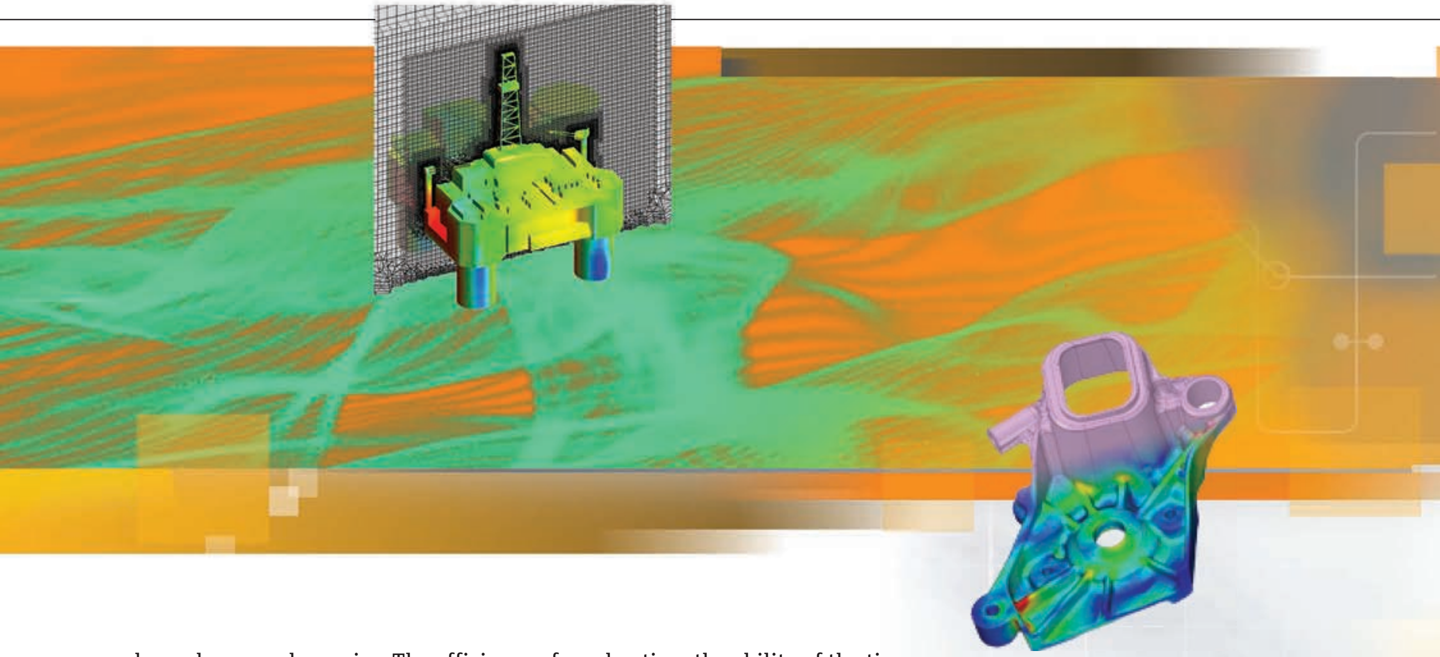
You might believe that engineering macro trends are only disrupting products such as cars, by increasing electrification and autonomy. However, this digital revolution is happening in every industry and for every product. Simulation is essential in this new world, because only by digitally simulating all the product options offered by these engineering trends can you gain the insight needed to innovate like the category leaders.


Today we see customers such as Mars, which makes Skittles® candy, use ANSYS software to optimize its manufacturing processes by leveraging the same simulation sophistication as turbine manufacturers. And startup Nebia used the same equations that govern rocket exhaust to save 70 percent of water consumption in a showerhead. No product is too small, simple or inexpensive to benefit from simulation.

## COMPLEX ANALYSIS FOR A COMPLEX WORLD

As we push for ever-smarter and more efficient product designs, we can no longer afford to only look at a single aspect of performance or a lone part in isolation. In the past, engineering simulation teams were likely to isolate just one critical physics — for instance, Formula 1 carmakers might have focused on the vehicle's aerodynamics, which has a profound impact on speed and performance.

Today, thanks to improvements in simulation software, hardware and processing speeds, it has become much easier for engineers to study multiple physics and assess overall product performance. This is critical because, to use the Formula 1 example, overall speed and performance do not only



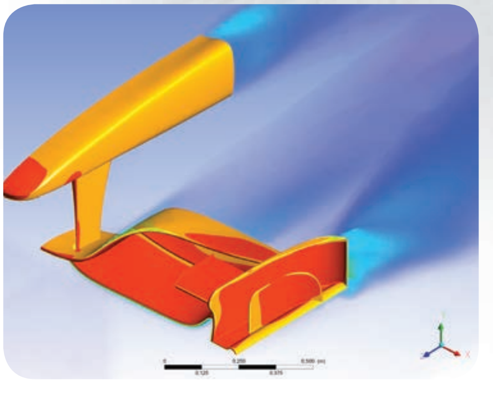
depend on aerodynamics. The efficiency of combustion, the ability of the tires to withstand wear, the reliability of electronics — all of these factors, and more, affect overall performance. Because optimization in one area might lead to a trade-off in another, it becomes increasingly important to simulate all influences together. Today, 96 of ANSYS's top 100 customers worldwide use three or more physics solutions, applied across the ANSYS platform.

Improvements in computing power and simulation software also allow the evaluation of many more design options, to the point where the design process can be turned upside down. Rather than asking simulation to verify a specific design, engineers are asking simulation to analyze thousands of possible designs, early in the ideation process, to identify the optimal one. This is perhaps most obvious in

**"Soon, *leveraging engineering simulation* pervasively will no longer be just a *competitive advantage* of the few, but an *absolute imperative* for all."**

topology optimization, where the engineer sets up, for example, the structural criteria for a part and simulation automatically iterates to find the best design.

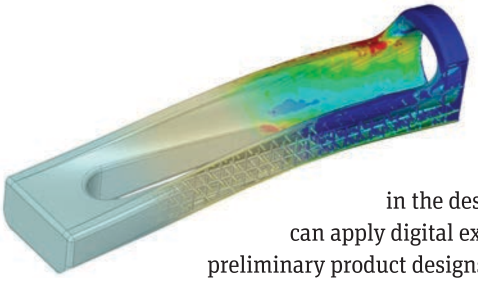
Increasingly, simulation will start from the requirements and generate the design, instead of being applied after most of the design choices have been made. This is the only way to tame the complexity inherent in modern product design, and to capitalize on the opportunities created by the rapid innovation required to be successful today.



## GENERATING RETURNS ACROSS THE PRODUCT LIFECYCLE

Probably the most important change today is a more pervasive, consistent use of simulation at all stages of a product's lifecycle. Once a specialized activity wedged between initial design and physical testing, today simulation is recognized for the significant strategic value and financial returns it can deliver from the earliest design phases through the product's working life in the field.

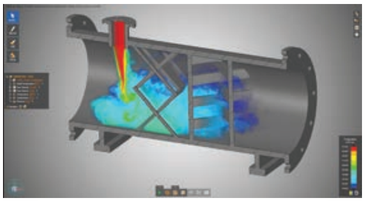
Even today, the majority of product decisions are made using rules of thumb, and simulation is primarily used by specialists within



the engineering team. Others still rely on the most used engineering tool, which is Microsoft® Excel. As simulation advances to become as easy and as fast to use as Excel, this opens a whole new era of innovation, in which every engineer can benefit from detailed simulation insights at any time in the design process. When products are in the earliest ideation stage, designers can apply digital exploration to test their initial concepts and gain insights that lead to preliminary product designs targeted at meeting highly defined customer needs, as well as earning strong profit margins.

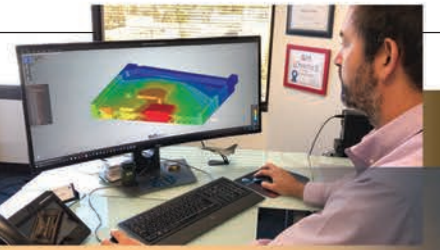
In a world where millions of rows of data are updated, calculated and charted in real time in Excel, and where Google gives us immediate access to billions of websites, it is almost incomprehensible that simulation is not equally accessible to every engineer. At ANSYS, we are making breakthroughs with Discovery Live and other products to make this a reality. In a few years, it will be unimaginable to innovate without native and pervasive use of simulation by every engineer.

Simulation is also increasingly applied to the manufacturing phase, where it significantly improves the efficiency, cost-effectiveness and flexibility of production. With the rise of mass customization of products — made possible by additive manufacturing, or 3D printing — simulation helps ensure that the finished product has the optimal shape and is made accurately, cost-effectively and with a high degree of consistency over time.



Additive manufacturing might enable us to produce almost any imaginable shape, but which is optimal? Can the human mind even conceive of the optimal shape? And, with mass customization, how do we ensure that every variation still preserves product integrity and performance? Simulation is key to unlocking the potential of 3D printing on a large scale by making it easy for companies to analyze on-demand and answer these questions to deliver unique, reliable, high-quality products with an extraordinary degree of confidence.

As the product moves from design and manufacturing into operations, simulation can continue to play a pivotal role in delivering the



> **"*Simulation* is being leveraged not just for *design validation*, but from *early ideation* through manufacturing, operations and maintenance."**

best possible results in the field. By using remote sensors to gather data on a product's working conditions, analysts create a virtual replica — a digital twin — of that product and then apply the same physical forces and other environmental conditions to the digital model. Applying simulation as part of a digital twin can provide vital insights in the form of virtual sensors, in situations where no physical sensor exists or would even be possible. Simulation also can run what-if studies for optimal performance, and can predict critical failure or maintenance requirements.

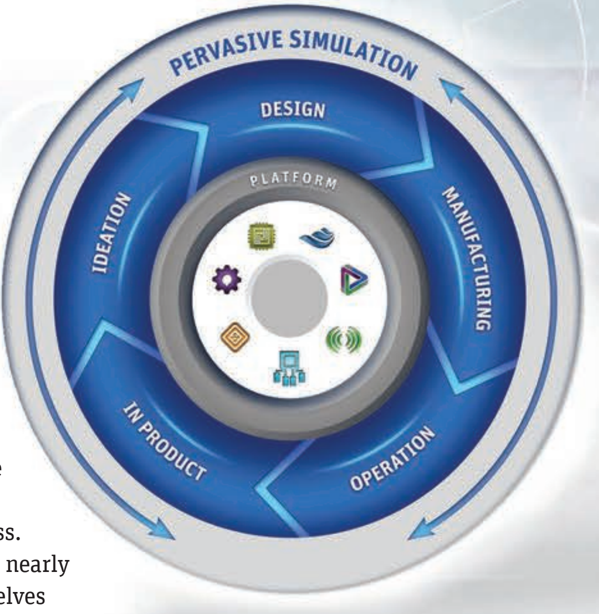
Digital twins are in their infancy today, but as Industry 4.0 matures, they will become increasingly commonplace, running on demand either in the cloud or on the asset itself. Increasingly, simulation will become an in-product experience in which the digital twin is an inherent part of the product's design and operation, working alongside artificial intelligence and machine learning algorithms.

## PERVASIVE SIMULATION: THE NEW IMPERATIVE

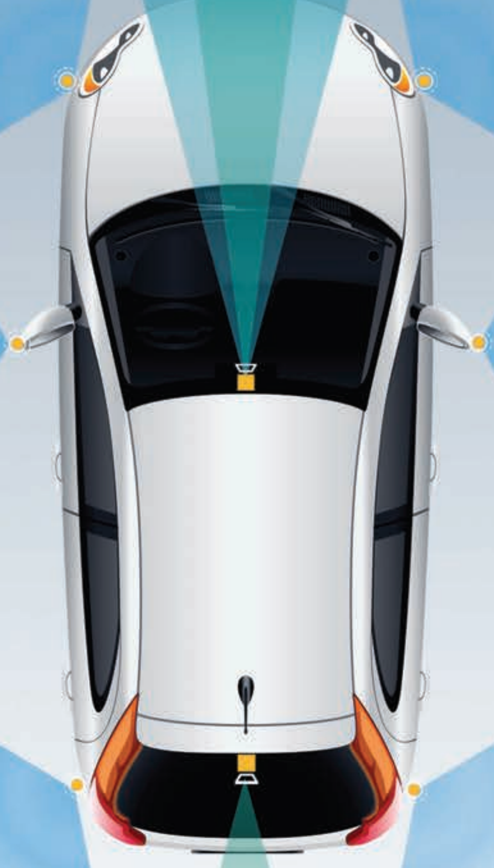
While not all companies are applying simulation to every product, studying the effects of multiple physics or leveraging simulation throughout the entire product lifecycle, these three trends signal the future. Leaders are already employing these best practices. Soon, leveraging engineering simulation pervasively will no longer be just a competitive advantage of the few, but an absolute imperative for all.

Ongoing improvements in simulation software make it easier than ever for a broad range of users throughout a business to apply these best practices. If you are currently using simulation only in your product development function, or only on certain designs, you are failing to realize the full potential of ANSYS software to deliver strategic and financial benefits for your business.

When engineering simulation software made its debut nearly 50 years ago, early adopters quickly distinguished themselves from those companies who were slower to recognize and embrace its potential. Tomorrow, it will be part of the toolbox for every engineer.



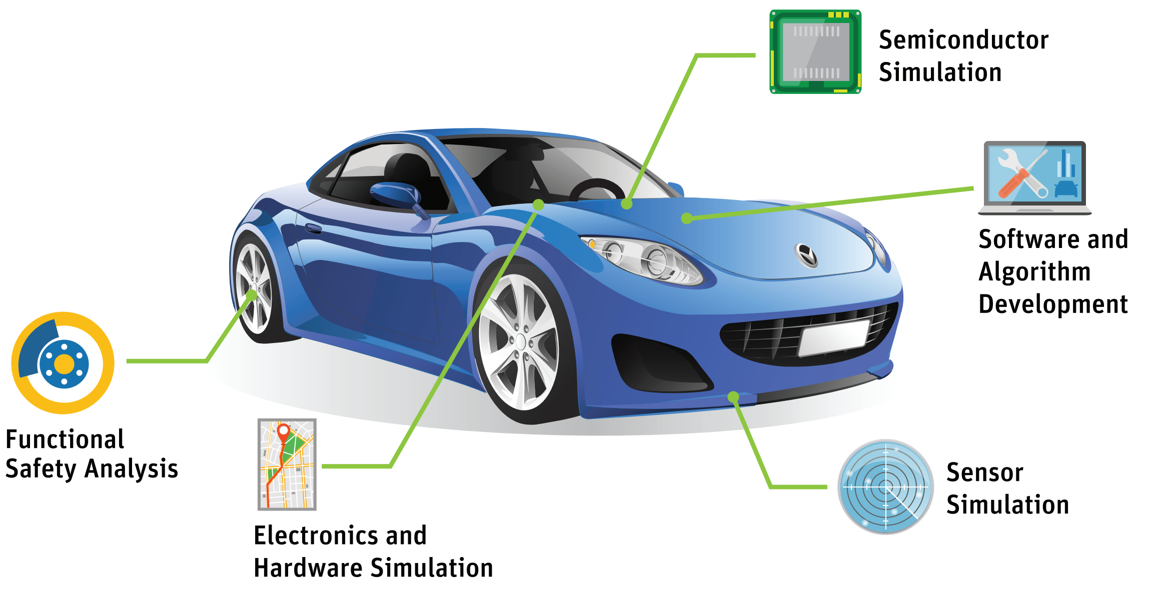
# Navigating Toward Full Autonomy



By **Scott Stanton**,
Director of Engineering Solutions,
ANSYS

For many years, cars and aircraft have featured some degree of assisted or partial autonomous functionality that we have trusted, whether an autopilot or an advanced driver assistance system (ADAS) such as blind spot detection. Today, time to market is of the essence, and the race is on to achieve full autonomy. This represents a step change in both engineering complexity and applicable safety criteria. Since conducting road-testing over the billions of miles required to demonstrate safety is time- and cost-prohibitive, companies have turned to simulation as the only way to successfully complete an autonomous vehicle program.

**Autonomous vehicles are proliferating, and not just in the automotive market. Companies like Amazon are investing heavily in drone delivery capabilities, while military organizations have utilized drone technology in combat situations for years. Manufacturers are using mobile autonomous robots in their production facilities, while transportation companies are developing tractor trailers that can run 24 hours a day, moving goods across thousands of miles quickly and cost-effectively. There is little doubt that autonomous vehicles are in our near future as consumers. However, getting there presents significant technology challenges for us as engineering professionals.**




Critical technologies for autonomous vehicles

There are good reasons to be excited about this trend. Autonomous vehicles and drone delivery promise to practically eliminate the element of human error, which caused 94 percent of the record-high 37,461 highway accidents that occurred in 2016.[1][2] As the degree of autonomy increases, the probability of human error declines significantly. Fully autonomous vehicles, supported by artificial intelligence and neural network algorithms, will enjoy a continuous 360-degree view of their surroundings — and those algorithms will never take a break to text their friends.

If we can replace flawed human behavior with fail-safe autonomous control — while consolidating our transportation investments — it only makes sense to pursue full autonomy for cars, drones and other machines. However, before this can happen within the bounds of engineering certainty, a number of technology challenges must still be solved.

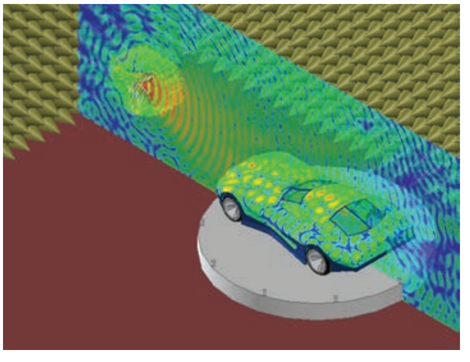
It has been estimated that demonstrating the safety of an autonomous vehicle could take over 8 billion miles of physical road testing.[3] In the race to achieve full autonomy, this is simply not practical. At the current rate of progress, road testing would take centuries to complete.

Engineering simulation is the answer, as it enables autonomous vehicles to be tested and verified in a risk-free, low-cost, time-efficient virtual environment. A recent safety report from Waymo — formerly the Google self-driving car project — described how its engineers are simulating the performance of a fleet of 25,000 virtual self-driving cars across more than 8 million road miles every day.[4]

**Fast-Tracking Autonomous Vehicles, Drones and Robots Via Engineering Simulation**
ansys.com/autonomy

> **"*Engineering simulation* is the answer, as it enables autonomous vehicles to be *tested and verified* in a risk-free, *low-cost*, time-efficient virtual environment."**

**Demonstrating Safety Through Closed-Loop Simulation**
At the highest level, these simulations must be able to capture the behavior of the vehicle in its environment. This can be characterized as a closed-loop simulation of the vehicle as it "sees," "thinks" and "acts," guided by artificial intelligence. The simulation includes virtual cities and roads, the sensors that function as the eyes and ears of the vehicle, the control software and algorithms that make critical decisions, and the vehicle dynamics, which are based on the instructions received from the software and algorithms. This simulation represents a continuous, closed-loop process through time, as the vehicle senses, executes and maneuvers through its journey.



Of course, these closed-loop simulations can only be considered reliable if they contain accurate representations of all the relevant components of the vehicle and its surroundings. There are five critical engineering capabilities that support an accurate virtual road-testing exercise:

- **Sensor design** based on the real-world conditions they must perform in
- **Semiconductor optimization** that balances high performance with risks such as electronics density and thermal build-up
- **Reliable electronics** designed to withstand actual operating environments
- **Safety-critical embedded software development** that integrates with machine learning and artificial intelligence components
- **Functional safety analysis** that minimizes the risks associated with component- or system-level failure


Each of these critical engineering applications is discussed as follows.

**Reliable Sensors for Real-World Perception**
Sensors are the eyes and ears of any autonomous vehicle, and thus are some of its most critical components. They are also among the most complex, tasked with gathering and processing large volumes of environmental data in real time and communicating this data to a perception algorithm. Common sensor types for autonomous vehicles include radar, lidar, cameras and ultrasound.

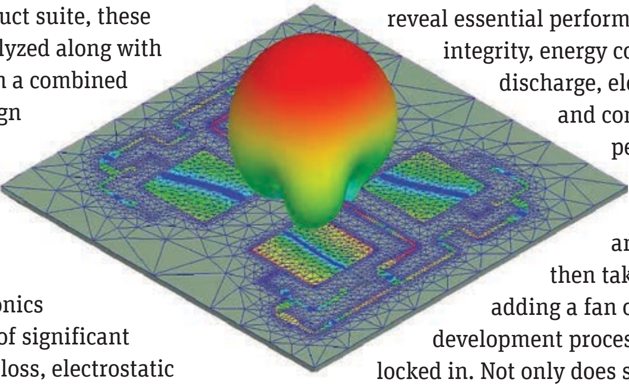
Testing and verifying the performance of the sensors represents a significant engineering challenge. For example, radar sensors are typically mounted behind the front fascia of an automobile. While perfectly controlled physical testing environments, such as anechoic chambers, can help engineers design these systems, the reality is that their radiation patterns will be skewed in real-world applications by the material properties and geometric configuration of a car's front fascia. To operate predictably and reliably on the road, radar systems must be designed to operate behind the front fascia of dozens of different types of vehicles, each with its own unique geometry and material properties. Physical building and testing is simply not practical due to the time and costs involved in each design iteration.

ANSYS offers a full suite of radar and antenna simulation solutions designed to replicate real-world performance with a high degree of fidelity. By leveraging ANSYS software, electrical engineers can predict sensor performance accurately — whether the sensor system is studied independently, mounted on a vehicle, placed into a static environment or studied throughout a fast-moving closed-loop simulation.

ANSYS also offers solutions for other sensor technologies, such as ultrasound, which is primarily used for parking assistance.

**Optimizing Semiconductor Performance**

ANSYS also enables the simulation of the semiconductor components that underlie radar systems and support signal processing. By leveraging the ANSYS semiconductor product suite, these semiconductors can be analyzed along with the surrounding circuitry in a combined chip–package–system design environment.



Semiconductors support much of the functionality of autonomous vehicles, yet the sheer number of electronics required can be the source of significant performance issues. Power loss, electrostatic discharge, electromagnetic interference, and thermal and structural stresses can all negatively impact product reliability and integrity. For example, a 25 C temperature increase typically leads to a 3-times to 5-times degradation in the expected lifetime of electronic devices.

ANSYS offers a number of specialized solutions, including ANSYS RedHawk 3DIC and PowerArtist, that can optimize the design of integrated circuits. These solutions help engineers manage electronics density and make intelligent trade-offs among product size, thermal build-up and overall product performance. The product development team can launch vehicles with the confidence that semiconductors will perform as expected in real-world operating environments.

**Electronics Reliability: Building Hardware to Last**

Advanced electronics hardware is one of the most critical components of any autonomous vehicle, supporting such key capabilities as communication, image and data capture, system control, artificial intelligence, and mobility. This hardware must be robust enough to withstand electrical, thermal, vibrational and mechanical stresses.

Instead of subjecting hardware prototypes to physical tests, engineers can apply a range of ANSYS tools — including Icepak, SIwave and Mechanical — to analyze packages, boards, enclosures and systems in a virtual design space. Simulations via ANSYS can reveal essential performance aspects such as power integrity, energy consumption, electrostatic discharge, electromagnetic interference and compatibility, thermal performance, and structural robustness.

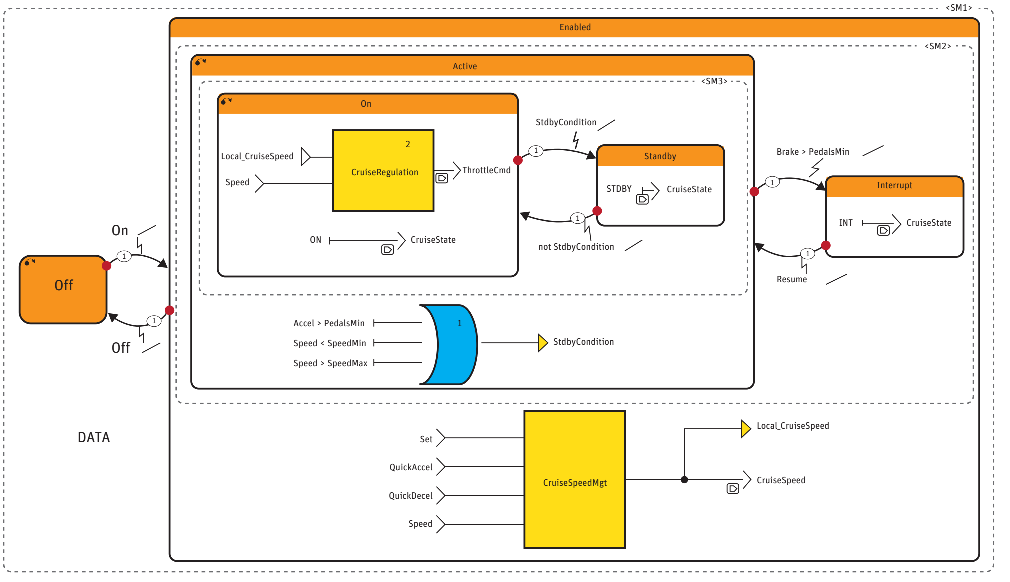
Based on their analysis, engineers can then take corrective actions — e.g., adding a fan or a heat sink — early in the development process, before final costs are locked in. Not only does simulation via ANSYS speed up the hardware design cycle and cut costs, but it also helps engineers avoid real-world performance problems associated with power dissipation, thermal overload and structural deformations, among other potential defects.

**Safety-Critical Embedded Software Development**

While invisible, computer software and its associated algorithms underlie the safe, reliable performance of every autonomous vehicle. For the vehicle to gather data and make intelligent decisions, every numerically based function — from signal processing routines to object recognition functions — must perform flawlessly. This means that the underlying software code must also be flawless.

To help eliminate human error, ANSYS offers its proven SCADE family of solutions for software development and verification. By numerically modeling and controlling all code-generation activities, SCADE solutions equip software engineers to meet industry safety standards and deliver high levels of performance. To support autonomous

**“As companies race to solve the remaining *engineering challenges* and launch *innovative*, yet practical, autonomous vehicles, *simulation* is a competitive imperative.”**




product development, SCADE solutions are designed for easy integration with third-party neural network and machine learning software.

In addition to improving the reliability of software code, ANSYS SCADE delivers significant improvements in development time and costs, as compared to manually based code-generation methods. Some customers report that software development time has been reduced by a factor of three by using ANSYS SCADE, as compared to a process without automatic code generation and verification.

### Functional Safety: An Automated Approach

No matter how rigorous the upfront engineering process, any electronic system can fail in the field. Unfortunately, this holds true for autonomous vehicles, where system-level failures can be catastrophic. Engineers need to build in a high degree of functional safety, which ensures that the overall system can respond appropriately should one component fail.

Because autonomous vehicles are composed of a multitude of mechanical parts, electronics, hardware and software, the process of functional safety analysis can be enormously complicated. Manual verification processes can be not only tedious and expensive, but are inherently prone to human error.

To address this problem, ANSYS offers the medini analyze solution family, which automates functional safety analysis and seamlessly integrates this critical activity into overall product development. Instead of working with assumptions about how the vehicle will perform in the event of a functional failure, engineers can evaluate potential failure modes using a fact-based method. They can then design a system-level response that mitigates the effects of that failure mode and protects human safety.

### Winning the Race

Today the question is not “Will we see fully autonomous vehicles transform multiple industries in the near future?” but “Who will be first?”

As companies race to solve the remaining engineering challenges and launch innovative, yet practical, autonomous vehicles, simulation is a competitive imperative. ANSYS is building the industry’s only comprehensive solution for simulating the performance of autonomous vehicles over the billions of miles they must be driven, flown or maneuvered.

Whether you are developing an entire vehicle or a component, simulation is relevant to your engineering challenges. ANSYS offers a single, configurable platform for validating vehicle performance against safety requirements. Its open nature integrates autonomous vehicle design into an ecosystem that includes, but is not limited to, high-fidelity physics studies, diverse sensor models, vehicle dynamics, world scenarios, embedded software code development, connectivity optimization, data analytics and functional safety analysis. Simulation software from ANSYS can be configured to a given development environment, hardware-in-the-loop requirements and the vehicle’s unique architecture.

Whatever challenge you are facing related to vehicle autonomy, we hope that you will find inspiration in this issue of *ANSYS Advantage*, as we profile some of the ground-breaking simulation work being accomplished by customers worldwide who are currently focused on winning this exciting race.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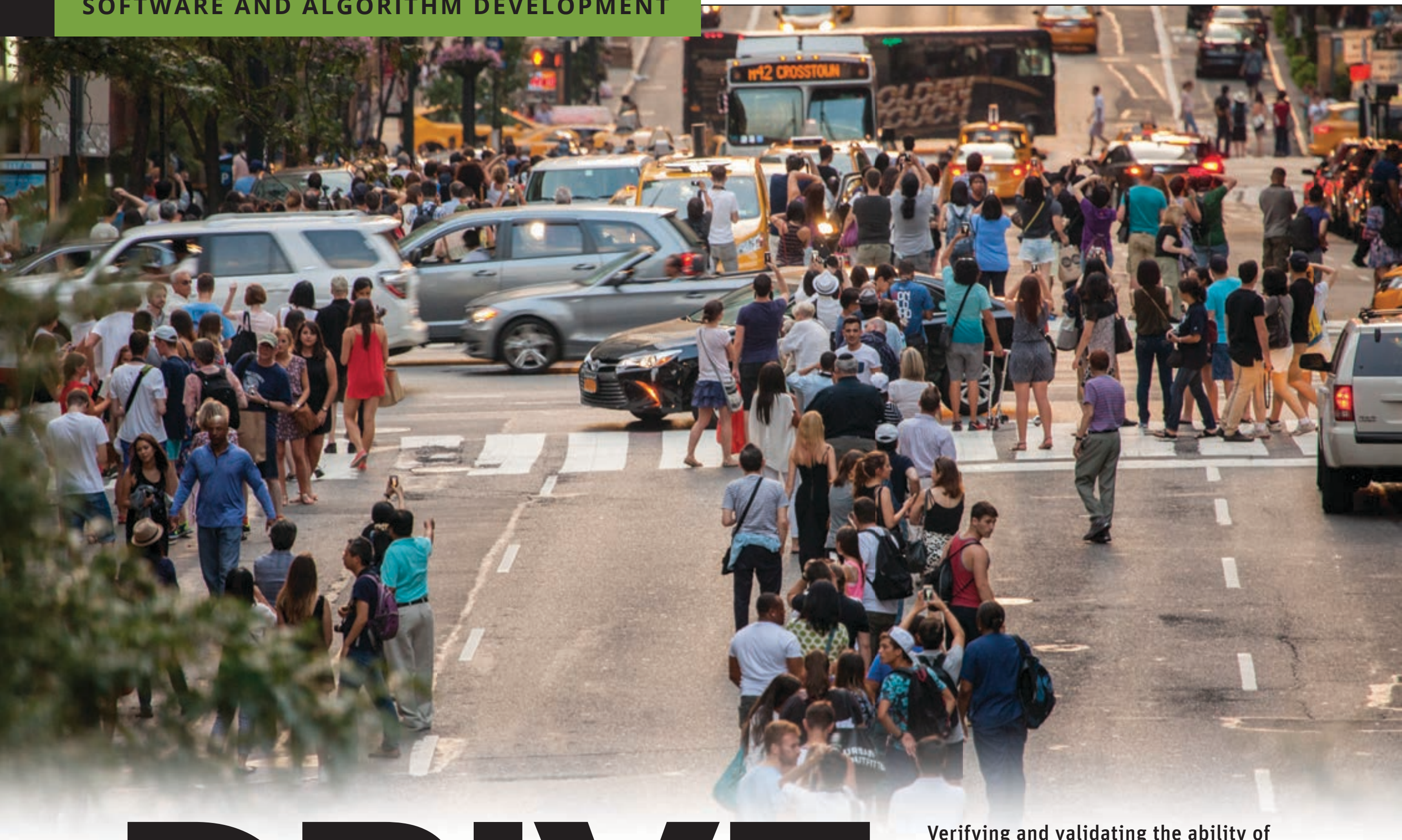


# DRIVE SAFELY

**Verifying and validating the ability of autonomous driving systems to operate in a complex environment presents an enormous challenge.**

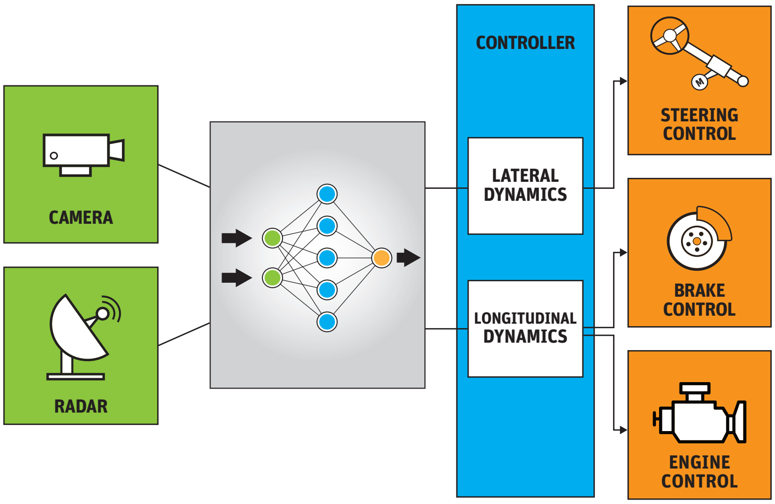
It would be impossible to program a computer to handle every possible driving scenario, so today's autonomous driving systems feature programs that learn and think like human beings to make the right decision for almost every situation. But how can these programs be verified for safety? The answer is by carefully designing an embedded software architecture that maximizes safety and a simulation platform that bombards autonomous driving software with billions of difficult driving cases to quickly identify its weaknesses.

By **Michael Wagner**, Chief Executive Officer, Edge Case Research, Pittsburgh, USA
**Bernard Dion**, Chief Technical Officer–Systems, ANSYS

Delivering an autonomous driving system, one that has the ability to understand every conceivable driving situation and make judgments to ensure the safety of vehicle occupants and pedestrians, is a complex and demanding task. For example, consider the challenge of developing rules for identifying any imaginable pedestrian, vehicle or other object that could appear on a city street. Conventional requirements-driven programming methods are not capable of mastering the huge number of potential situations that could occur on today's roads and highways.

Hands-off autonomous driving systems rely upon deep learning algorithms that can be trained to develop human-like capabilities to recognize patterns without having to be exposed to every possible situation that could arise on a trip to the grocery store. These systems lack the defined detailed requirements



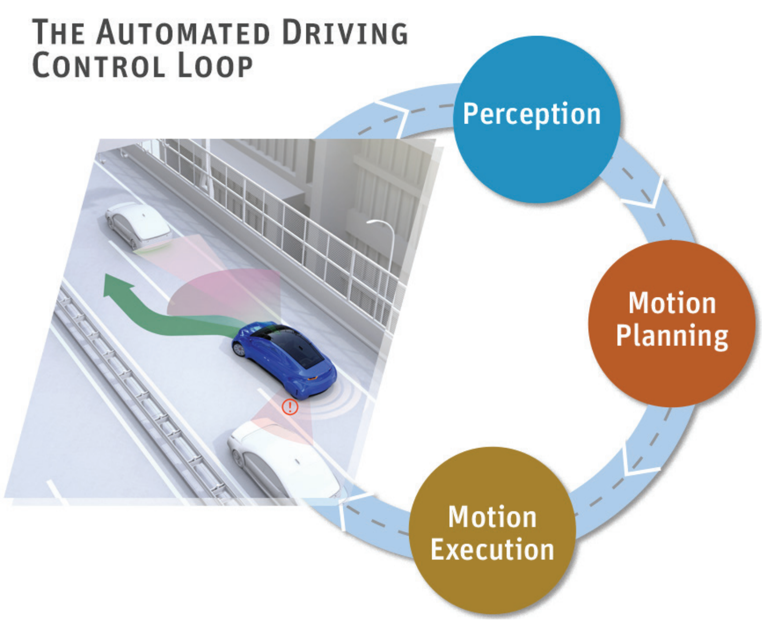

**Conventional software cannot do the job, so machine learning and deep learning are at the heart of the latest autonomous driving software.**

and architecture that are used to validate conventional safety-critical software. Road testing is not a practical verification method because billions of miles would be required to demonstrate safety and reliability. The ANSYS ADAS/autonomous vehicle open simulation platform integrates physics, electronics, embedded systems and software simulation to accurately simulate complete autonomous driving systems. By linking the ANSYS simulation platform and ANSYS SCADE model-based development tools with Switchboard™ automated robustness testing technology from Edge Case Research (ECR), together with ANSYS medini functional safety analysis, it is possible to achieve end-to-end safety in autonomous driving systems, including those that use deep learning.

**From ADAS to Autonomous Driving**

Advanced driver assistance systems (ADAS) are increasingly being used in today's automobiles to alert drivers to potential problems or even to take control of the vehicle to avoid a collision. These safety systems are normally validated using the system and embedded software lifecycle V-model defined in ISO 26262. Using the V-model, developers carefully define the detailed requirements and architecture of the system and then methodically verify the ability of the system to meet each of the requirements. The ANSYS SCADE Suite complete end-to-end model-based system engineering (MBSE) solution is used in the development of safety-related systems for leading automobile manufacturers.

Developing a fully autonomous driving system is much more sophisticated, and must be based on a combination of machine learning/deep learning and control logic to implement the full autonomous vehicle control loop. The control loop is composed of perception (what the car observes), motion planning (what behavior the car is planning) and motion execution (how the car will complete the plan). This control loop is executed in a cyclic fashion so that the vehicle can respond to constant changes in the environment. But autonomous driving systems based on machine learning can only be released to the public after developers have demonstrated their ability to achieve extremely high levels of safety. Road testing is clearly an essential part of the vehicle development process, but it is not the answer to safety validation. The problem is that road testing primarily consists of routine occurrences that are not difficult for human or autonomous drivers. Billions of miles of road testing would be required to validate



> **"Hands-off *autonomous driving systems* rely upon deep learning *algorithms* that can be trained to *recognize patterns* without having to be exposed to every possible situation."**

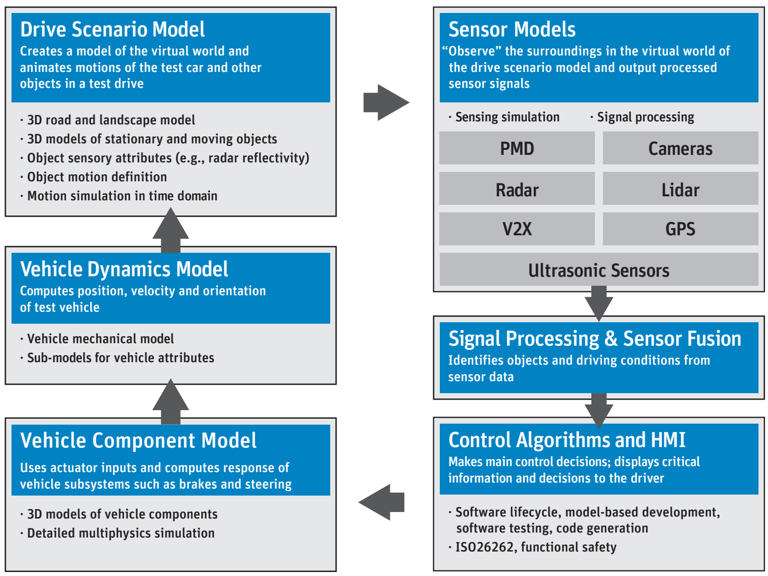
safety, and, even then, a failure or a change of code would potentially require starting over from zero.

### Overcoming the Safety Verification Challenge

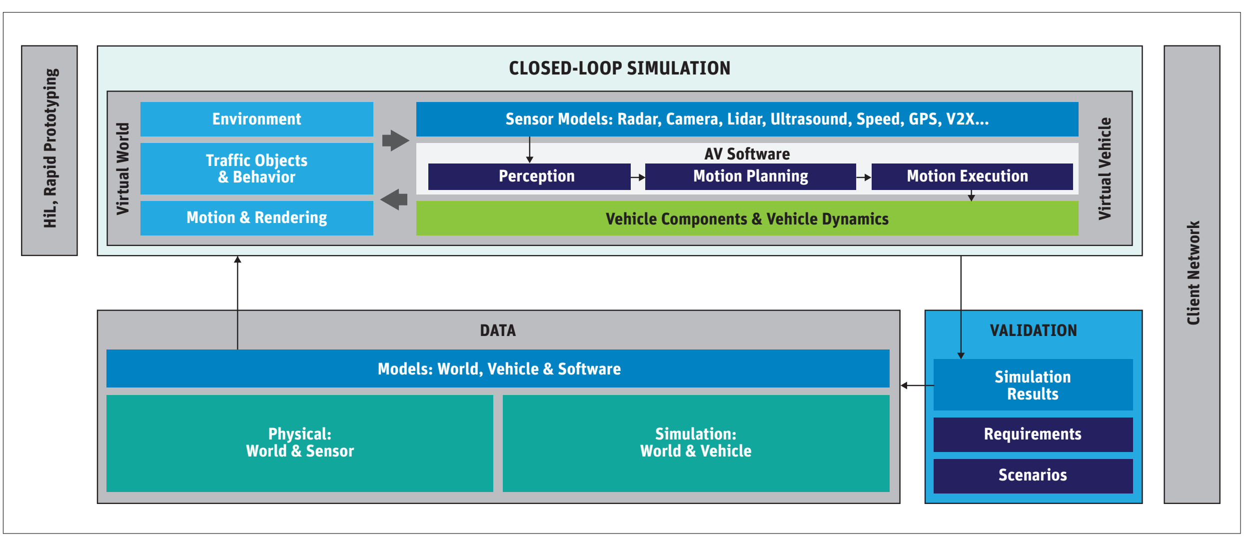
The ANSYS ADAS/autonomous vehicle open simulation platform can test many more scenarios in a fraction of the time and cost required for road testing by incorporating:

- Simulation of driving scenarios, including modeling of both the virtual world in which the autonomous car is operating and the virtual vehicle itself with accurate sensor simulation (radar, lidar, cameras, GPS, etc.) as well as vehicle dynamics.
- ISO 26262 qualified model-based development tools for control and human machine interface (HMI) software.
- Optimization of the signal integrity, thermal, structural and electromagnetic reliability of semiconductors and electronics systems.

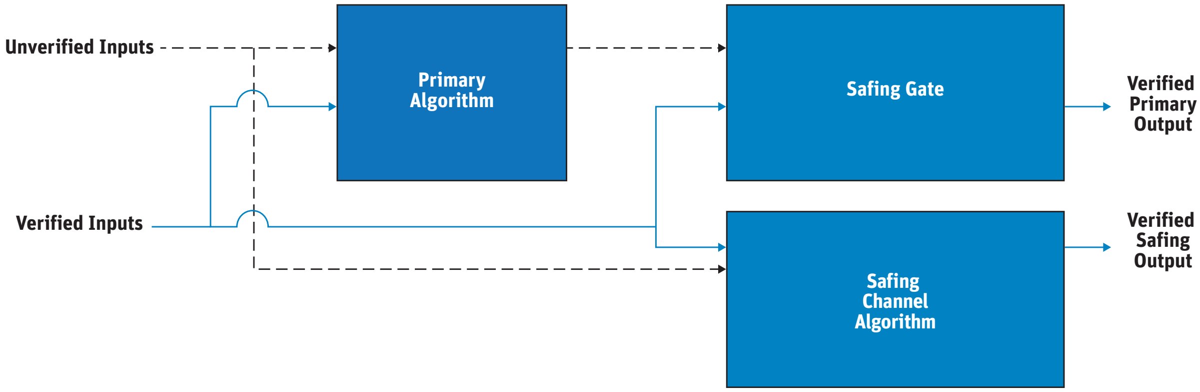
The integration of all physics, embedded systems, software simulation and code generation enables developers of autonomous systems to accurately simulate the complete automated driving control loop on a single platform. The drive scenario model animates the motion of the test car and other vehicles and objects in a test drive. Sensor models observe the surroundings in the




Simulation of the automated driving control loop

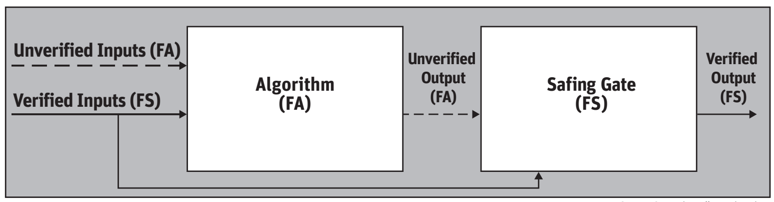



ANSYS autonomous vehicle simulation architecture




**The primary channel produces a long-duration mission with no defined end state, while the safing channel produces a short-duration mission that ends in a safe state.**

virtual world and output sensor signals. Signal processing models and deep learning identify objects and driving conditions from sensor data. Control algorithms make control decisions, generate actuator inputs, and display information and decisions to the passenger/operator. Vehicle component models use actuator inputs and compute the response of vehicle subsystems such as steering and braking. The vehicle dynamics model computes position, velocity and orientation of the test vehicle.




Source: Carnegie Mellon University

The algorithm (the "DOER") can fail arbitrarily (FA) meaning it can do wrong things in the worst possible way.

The safing gate (the "CHECKER") turns the algorithm into a fail silent (FS) component, only producing correct data or shutting down.

**The safing algorithm for the planning phase**

### Safe Architecture for Safe Vehicles

While simulation is far faster and more efficient than road testing, it does not on its own answer the question of how to verify the safety of the complex autonomy algorithms used for perception, motion planning and execution functions.

To do this, first engineers must break down the overall autonomous vehicle software architecture into a meaningful set of components based on perception, planning and execution. Next, they must design an architecture that will guarantee safety for each of these components. This architecture is based on a DOER-CHECKER principle.

The detailed architecture is composed of a primary algorithm (DOER) that may be extremely complex, undergo frequent updates and be difficult to verify. This primary algorithm is paired with a corresponding safing gate (CHECKER) that verifies that the outputs of the primary algorithm are correct. If the safing gate detects a problem, a safing channel algorithm takes control. This can be the basis for the two-channel architecture developed by members of the ECR team while at Carnegie Mellon University (see diagram). This architecture comprises a primary channel that produces a long-duration mission and a safing channel that produces a short-duration mission, such as pulling the car to the side of the road.

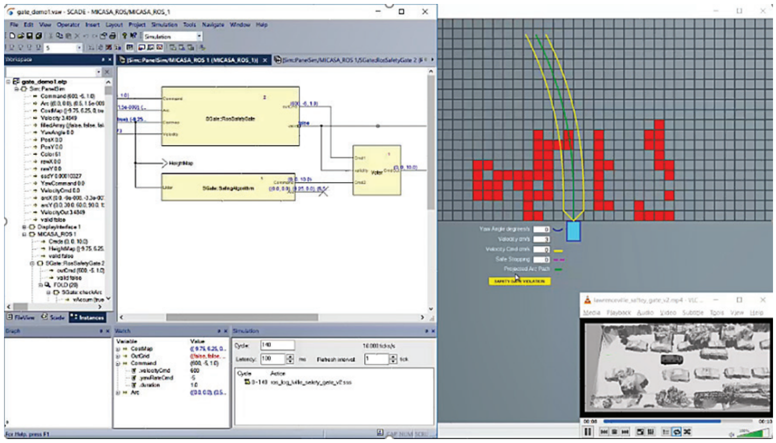
Using this architecture, the plan can be checked for safety during the planning phase. The primary algorithm need not satisfy safety objectives at the highest level (ASIL D in ISO 26262); rather, this responsibility is allocated to the safing gate. What makes this possible is that the detailed safety requirements of the safing gates can be established so that their implementation meets the objectives of ISO 26262 at ASIL D. This is depicted by the example shown, in which the car is going to stop because a double-parked car has been detected.

### Automated Robustness Testing Identifies and Diagnoses Failures for Perception

Assuring the safety of perception is more complex; it is not possible to create a safing gate to check that perception outputs are correct and safe. Therefore, safety of perception must be validated using different techniques. ECR Switchboard addresses this challenge (and some others) by providing automated robustness testing to find failures.

What is needed to prove perception safety is large-scale exposure to the difficult cases that can challenge autonomous driving systems (and often human drivers). ECR Switchboard uses a novel algorithm to cut through the potentially endless number of possible tests to quickly find test cases that cause software to fail and understand why the failure occurred. It sifts through the high-dimensional input space to identify exceptional queries that are informative for testing the model. It bombards the automated driving system with a mixed stream of nominal and exceptional inputs until a failure occurs. The failures are then diagnosed by generalizing a single fault-triggering input to produce a set of inputs that serve as hints in implicating field-value assignments in triggering the failure. This approach is highly effective at finding edge cases that cause system failures.

Perhaps the greatest challenge remaining in the large-scale deployment of autonomous driving systems is testing and debugging machine learning and deep learning algorithms that work without defined requirements and design to ensure their robustness and safety. ANSYS has leveraged its vast experience in multiple physics simulation and simulating safety-critical embedded software to deliver a complete automatic driving simulation platform that includes the world's only ISO 26262–compliant code generator. This platform is now integrated with the ECR Switchboard robustness testing platform, which runs huge numbers of simulation scenarios while biasing toward difficult scenarios to mitigate residual safety validation risk. This partnership can deliver a complete solution to verify and validate the safety of the most advanced autonomous driving systems.



**ECR Switchboard identifies perception failure: strong detection becomes extremely weak after barely perceptible environmental changes. The deep-learning algorithm can be augmented under test using any failures the Switchboard finds.**

**"The ANSYS/ECR partnership can deliver a complete solution to verify and validate the safety of the most advanced autonomous driving systems."**

**ECR switchboard finds a path planning failure**

**Analysis and Development of Safety-Critical Embedded Systems: The Need for an Integrated Toolkit**
ansys.com/safety-critical


# Safe Travels

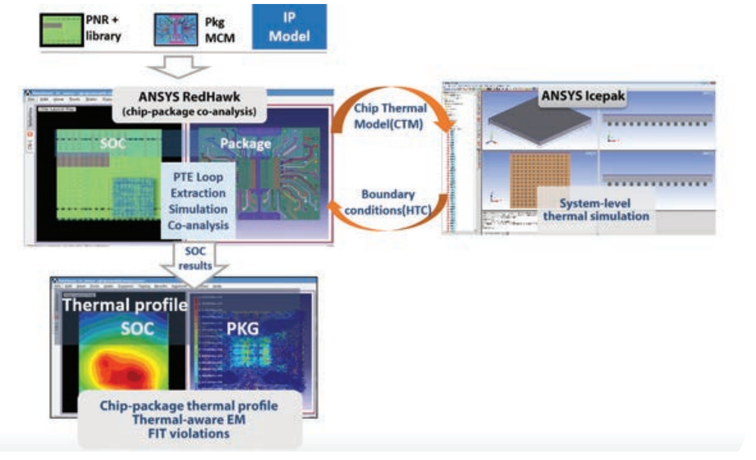
**AUTOMOTIVE ELECTRONICS** have always had to withstand difficult environment conditions. Today, with the safety of the vehicle's occupants increasingly dependent on these same electronics, the consequences of failure are greater than ever before. Engineering simulation is essential to diagnose and validate automotive electronics reliability before investing in expensive prototypes and field testing.

By **Arvind Vel**, Director, Semiconductor Product Management, ANSYS

As automotive electronics' role transitions from entertaining the driver to assisting the driver, to taking full control of the vehicle, its reliability is coming under increasing scrutiny. Critical automotive electronic systems need to last more than 10 years, often under hostile underhood environments where temperatures can range up to 150 C. ANSYS simulation tools enable engineers to simulate, debug and optimize proposed electronic systems designs with respect to issues that might cause an automated driving system to fail. Simulation makes it possible to design robust and efficient electronic systems that meet demanding reliability requirements for autonomous driving applications. This article will focus on the varied aspects of reliability and chip–package–system (CPS) simulations that enable package/system-aware integrated circuit (IC) design and IC-aware package/system design.

## Autonomous Driving Reliability Challenges

Today's drivers increasingly depend upon electronic systems to ensure safety. For example, nearly every car uses an anti-lock braking system to reduce stopping distance in slippery conditions. The recent proliferation of advanced driver assistance systems (ADAS) capabilities, such as applying the brakes automatically if the vehicle ahead stops or slows suddenly, have further increased the importance of electronics in vehicle safety. Of course, the emergence of autonomous driving systems that understand every conceivable driving situation and make judgments to ensure the safety of vehicle occupants and pedestrians will further increase the dependence of driver, passenger and pedestrian safety on automotive electronics.



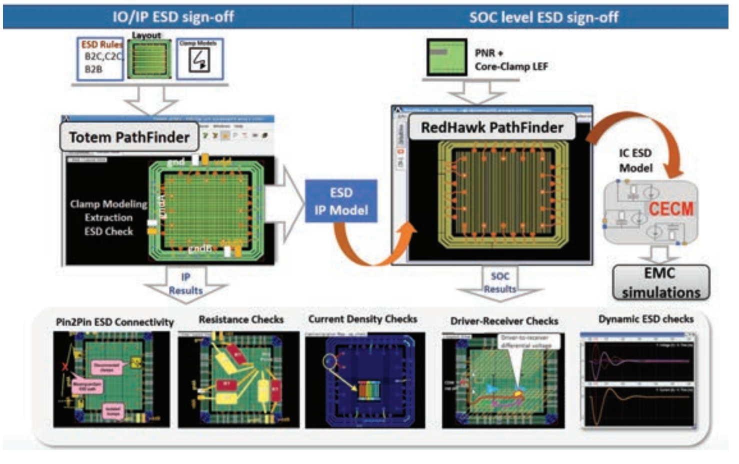

ANSYS chip–package–system thermal reliability analysis with ANSYS RedHawk-CTA and ANSYS Icepak

Many current automotive electronics applications reside on semiconductors based on older process nodes that are relatively easy to validate from a reliability standpoint because of their large feature size and the experience of designers. However, the sensors used in ADAS and autonomous driving technology generate

*"Simulation makes it possible to design robust and efficient electronic systems that meet demanding reliability requirements for autonomous driving applications."*

huge amounts of data (40 gigabytes per hour is not unusual) that must be processed at blinding speeds and with low latency. These applications require vast increases in computing power that can be satisfied only by leading-edge semiconductor processes with much smaller feature sizes that are just now reaching the market.

The new generation of integrated circuits, designed in advanced process nodes, pack more transistors into a smaller footprint to deliver the highest possible levels of computing performance. These ICs operate at much lower supply voltages, making them more susceptible to power and signal noise coupling. Another challenge is that in many cases these semiconductors will need to operate in underhood environments where ambient temperatures can reach up to 135 C, which makes them more susceptible to thermal-induced failures. This thermal challenge is intensified because electronic components in many automotive applications are exposed to water and dirt, so they must be sealed against the elements. This increases the difficulty of providing adequate cooling.

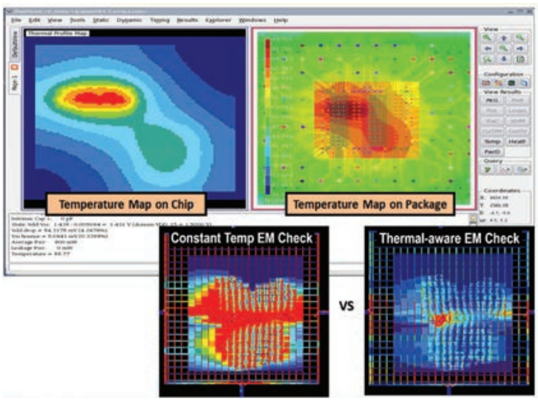



ANSYS PathFinder ESD/EMC workflow

*"The ability to identify and troubleshoot reliability issues with simulation makes it possible to achieve substantial reductions in time to market and to improve reliability."*

## Electromigration

The proliferation of automotive semiconductors based on leading-edge process nodes that enable ADAS and autonomous driving makes electromigration — a lifetime reliability problem — a critical system design issue. Electromigration (EM) occurs when electrons flow through an integrated circuit and collide with the metal atoms in the conductors and gradually create an open or a short. Over time, this causes the chip to fail. Chips become more susceptible to EM as their conductor cross section shrinks at each successive process node. EM also exponentially increases as a function of temperature. Advanced 2.5D and 3D integrated circuits are bringing dies closer together, creating the potential for more thermal hot spots.

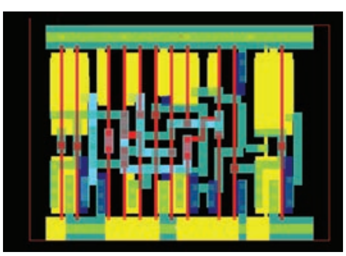


Thermal analysis of chip and package using ANSYS RedHawk-CTA

Typically, the temperature of the individual conductors on a chip is not known, so design engineers assume a uniform worst-case temperature across the chip. This approach was satisfactory at older process nodes, but the faster switching speeds, narrower conductors and higher number of layers within today's advanced process nodes greatly increase the number of EM violations when this approach is used. Design teams spend increasing amounts of time evaluating and fixing these violations, many of which are false and would never have been triggered if the simulation had been based on an accurate nonuniform temperature profile.

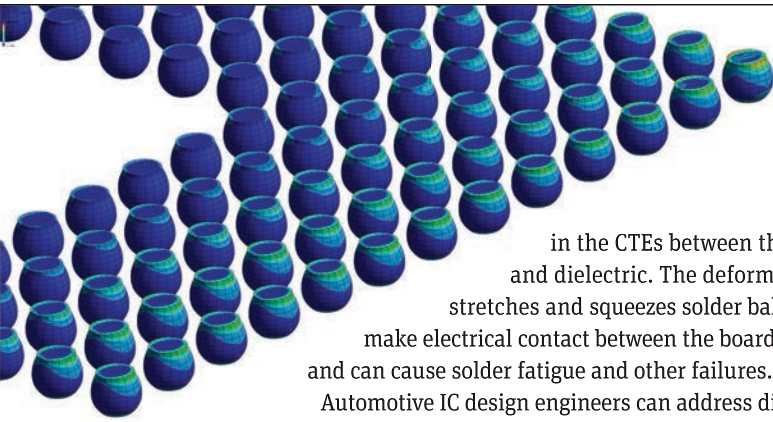
The ANSYS RedHawk platform addresses these challenges by accurately determining the increase in temperature around the devices and metals to accurately predict EM violations. This increase in temperature is modeled using the Joule self-heat and thermal coupling principles between metal conductors inside a chip. The device temperature is a function of the amount of current consumed by each transistor as well as the proximity to neighboring transistors. Process parameters from the foundry combined with thermal characteristics of the metals and dielectrics used on the die are used to accurately predict the localized temperature changes.

The temperature profile is used to perform thermal-aware EM checks based on the actual temperatures experienced by each wire on the chip. This approach greatly reduces the number of EM violations while providing much more diagnostic information than was available in the past to aid in addressing them. Engineers can zero in on the EM violations that really matter and can fix these violations faster. The result is a significant reduction in time to market and a lower risk of EM failure.

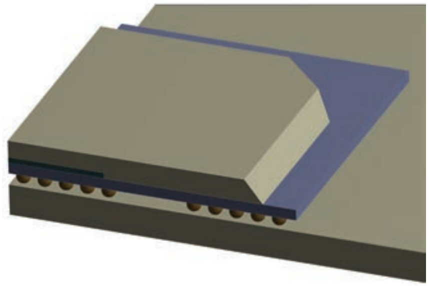

Wire temperatures used to calculate thermal-aware electromigration

## Thermal Performance

Thermal effects are another major concern in ensuring the reliability of critical automotive semiconductors. At the die and package level, engineers need to ensure that the temperatures across the chip do not exceed maximum operating temperatures at any point. Furthermore, they must evaluate thermal cycles during operation that generate deformation on the die and package because of differences in the coefficients of thermal expansion (CTEs) between the wafer and the metal layer. Thermal cycles at the board level can also generate stress due to differences



ANSYS Mechanical predicts the impact of temperature on stress, strain and deformations on the die.



in the CTEs between the copper and dielectric. The deformation stretches and squeezes solder balls that make electrical contact between the board and chip, and can cause solder fatigue and other failures.

Automotive IC design engineers can address die-level thermal reliability issues using ANSYS chip thermal models (CTMs) to solve for a complete chip-and-package co-analysis. The temperature profiles from the analysis can then be used inside ANSYS Mechanical to predict the impact of temperature on stress, strain and deformations generated by thermal or mechanical loading on the die. At the board level, the ANSYS SIwave signal integrity analyzer can be used to compute Joule heating in printed circuit board (PCB) traces and vias to create a board trace map and current density predictions. This is exported to the ANSYS Icepak systems-level thermal simulation tool, which calculates the orthotropic thermal conductivity of the PCB and temperatures at every point in the solution domain. These temperatures are transferred back to SIwave to update the electrical properties of the board based on the temperature field. SIwave and Icepak then iterate until the temperatures converge. The temperatures are used to load a structural model of the board and predict stresses and deformations.

**Electrostatic Discharge**

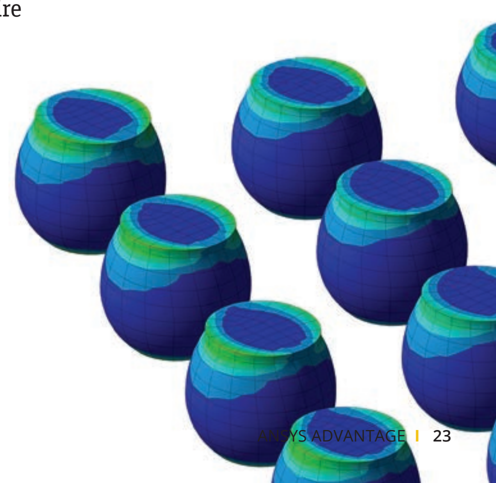
The smaller feature sizes and isolated and independent power/ground networks often found in advanced process nodes increase the risk of electrostatic discharge (ESD) failures. The traditional approach to ESD verification involves following engineering guidelines in creating the layout and running design rule checks. But these methods cannot predict if the overall resistance and current density of the ESD paths are below the threshold limit.

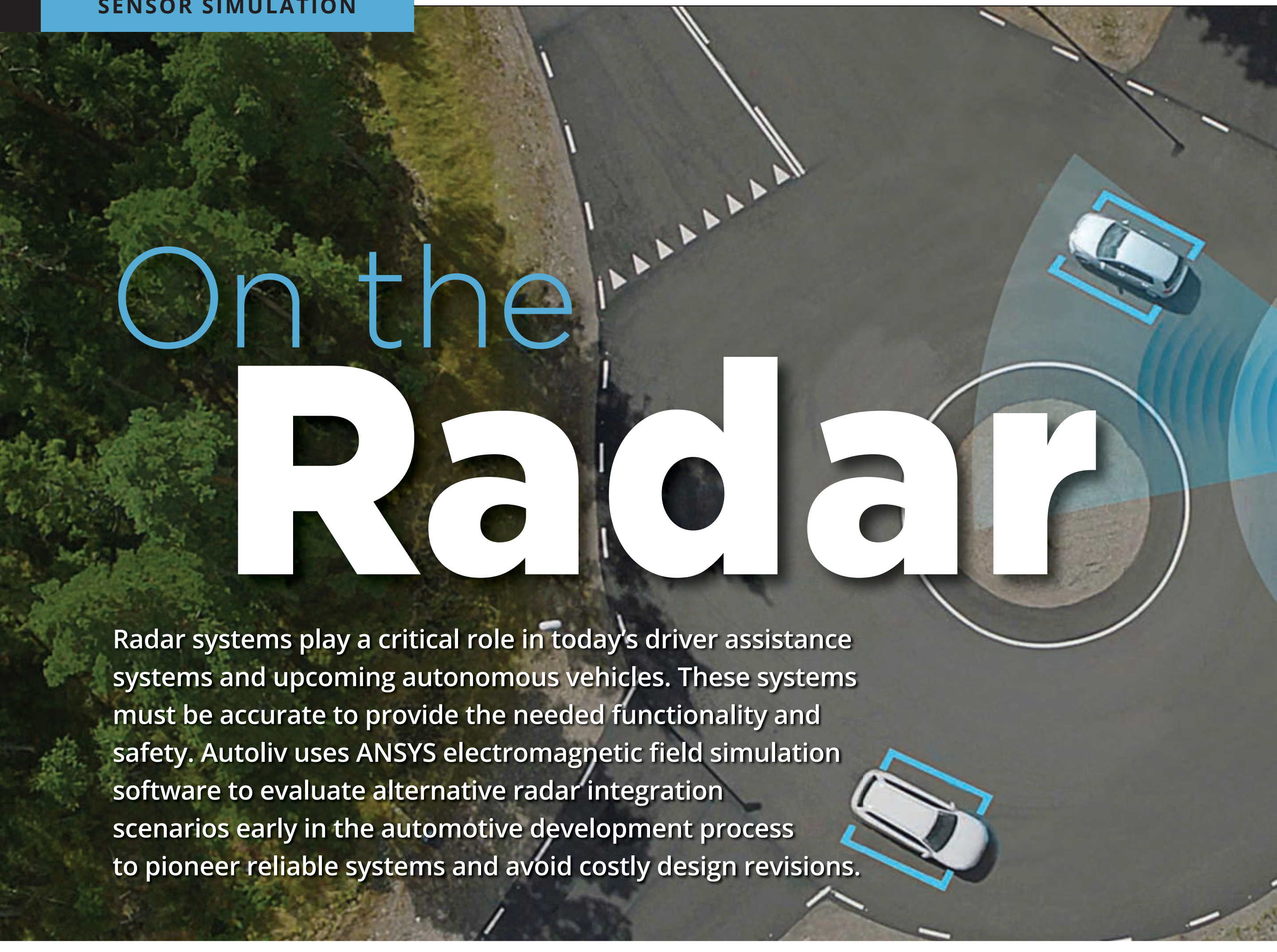
ANSYS PathFinder uses block-level static and dynamic techniques as well as full-chip level static methods to identify weak areas in the design and determine whether or not it meets ESD guidelines. PathFinder verifies the effective resistance between any two pads/bumps traversing the network through a clamp cell; between pads/bumps to every connecting clamp cell; between multiple clamp cells; and between active devices and clamp cells for pass/fail checks. PathFinder estimates the effective resistance from the devices in the IC to the clamp cells that are inserted to provide a discharge path. PathFinder highlights the wire/vias that fail the current density limits, allowing the designers to verify that the current flow during a discharge event is within the established limits defined by technology or process guidelines.

*“The safety of ADAS and autonomous driving systems is only as good as the reliability of the electronic systems they run on.”*

The safety of ADAS and autonomous driving systems is only as good as the reliability of the electronic systems they run on. ANSYS simulation tools enable engineers to perform EM analysis based on the temperature experienced by each wire on the chip. This approach saves time by highlighting the truly problematic traces. ANSYS thermal simulation tools further enable engineers to evaluate the complete thermal ecosystems to identify and correct thermal problems at the die, package, board and system level. Finally, ANSYS simulation tools enable engineers to identify and troubleshoot ESD problems. The ability to identify and troubleshoot reliability issues with simulation enables companies to ensure the reliability of ADAS and autonomous driving electronics in a rigorous yet efficient fashion, making it possible to achieve substantial reductions in time to market and improving reliability.

**Fast Tracking ADAS Autonomous Vehicle Development with Simulation**
ansys.com/fast-tracking





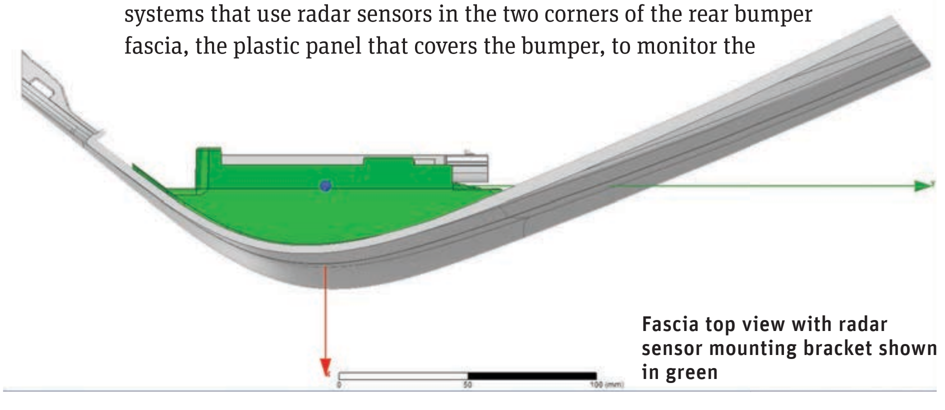
# On the Radar

Radar systems play a critical role in today's driver assistance systems and upcoming autonomous vehicles. These systems must be accurate to provide the needed functionality and safety. Autoliv uses ANSYS electromagnetic field simulation software to evaluate alternative radar integration scenarios early in the automotive development process to pioneer reliable systems and avoid costly design revisions.

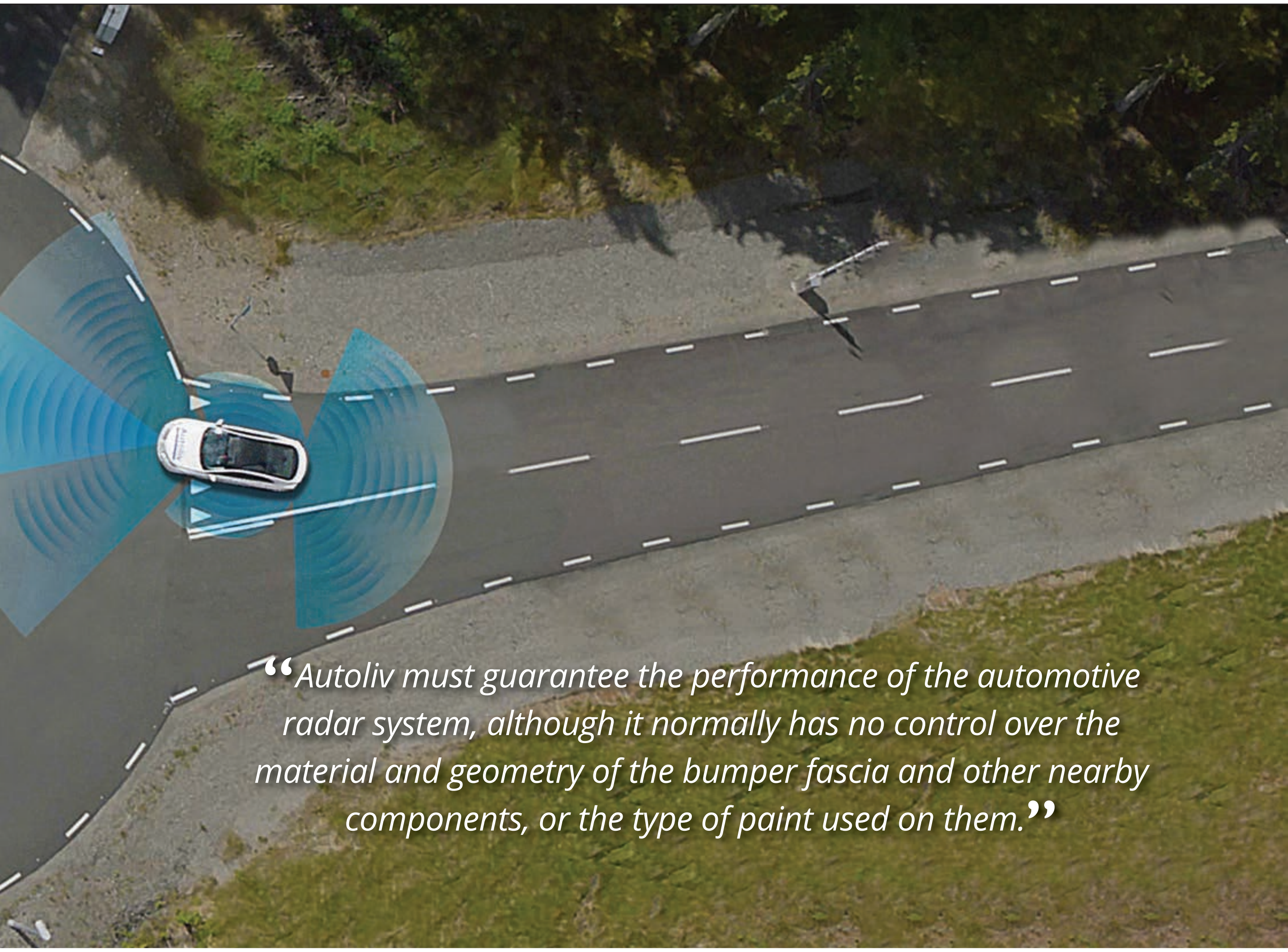
By **Clyde Callewaert**,
Principle RF Engineer,
Autoliv Electronics,
Southfield, USA

Vehicle safety and autonomous driving require ever-increasing numbers of radar systems looking outward at the vehicle's environment. The packaging design of these radar systems is carried out early in the vehicle development process, before a prototype vehicle is available for performance testing. If engineers get the design wrong, the packaging process may have to be repeated at a cost of about $1 million and possible delays to the vehicle launch. Autoliv, the worldwide leader in automotive safety systems, avoids these costs by using ANSYS HFSS to predict how the fascia and other nearby components affect radiation patterns so they can validate the design long before the prototype phase.

For example, many of today's vehicles are equipped with blind spot detection systems that use radar sensors in the two corners of the rear bumper fascia, the plastic panel that covers the bumper, to monitor the



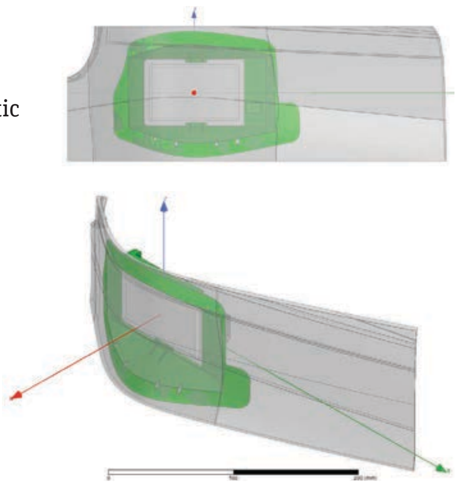
Fascia top view with radar sensor mounting bracket shown in green



*"Autoliv must guarantee the performance of the automotive radar system, although it normally has no control over the material and geometry of the bumper fascia and other nearby components, or the type of paint used on them."*

presence, direction and speed of vehicles in adjacent lanes. If a vehicle is present in either of the driver's blind spots, a warning indicator on the side view mirror lights up. Many current vehicles also have a radar sensor in the middle of the front bumper to enable features such as forward collision warning, which detects vehicles or objects that the driver might hit if not noticed. Fully autonomous vehicles are expected to have these and more radar systems mounted behind the bumper fascia and other body panels.

Radar systems use a transmitter to emit a short pulse of electromagnetic radiation. After each pulse, the transmitter is turned off and a receiver listens for signals caused by the pulse reflecting off nearby objects. Electromagnetic radiation emitted by a radar sensor may be distorted in difficult-to-predict ways by objects that the radiation must pass through. Other nearby objects may generate reflections that interfere with the receiver. When integrating a radar sensor in a new vehicle, engineers must position the system so that the fascia and mounting bracket do not interfere with its accuracy. This means obtaining a high and relatively constant signal across the azimuth (from side to side) of the sensor while minimizing wasted energy delivered to undesired directions or reflected by the bumper fascia back to the radar. The geometry of the bumper fascia is often complex because it has to meet multiple goals that include durability, safety, aesthetics and manufacturability. A slight change in sensor position can be the difference between meeting or not meeting accuracy requirements. Autoliv must guarantee the performance of the



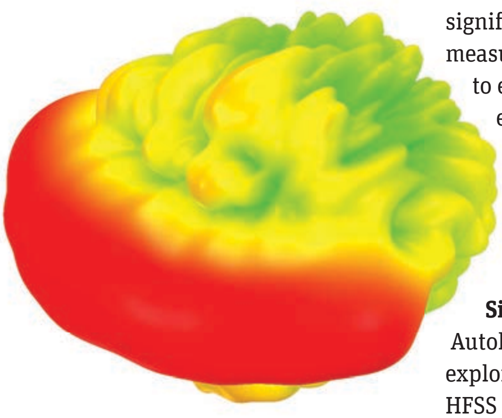
Truncated section of CAD file of bumper fascia used for simulation, with radar sensor position

*“If, during drive testing, Autoliv engineers discover that the position of the radar or bracket geometry makes it impossible to meet the performance requirements, the entire process must be repeated at a cost approaching $1 million.”*

automotive radar system, although it normally has no control over the material and geometry of the bumper fascia and other nearby components, or the type of paint used on them.

**Impact of Packaging Design on Radar Accuracy**

To meet the vehicle launch date, Autoliv must first create the packaging design. This mainly consists of determining the best position for the sensor in relation to the fascia and designing the mounting bracket, before the vehicle or even the fascia is available for testing. Autoliv invests significantly in packaging design, instrumenting the vehicle prototypes with measurement equipment and in test driving in many different environments to evaluate the accuracy of the radar. If, during drive testing, Autoliv engineers discover that the position of the radar or bracket geometry makes it impossible to meet the performance requirements, the entire process must be repeated at a cost approaching $1 million. The additional design iteration also adds eight to 12 weeks in lost program time, which could potentially delay the vehicle launch.

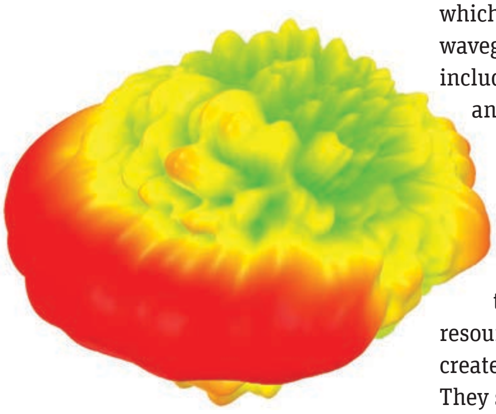


Sensor transmit radiation pattern without fascia

**Simulating Radar Performance in the Vehicle**

Autoliv avoids this potential problem by using ANSYS HFSS to digitally explore and evaluate radar sensor packaging designs before prototyping. HFSS has demonstrated predictive power in many different programs and applications. The simulation process begins by obtaining physical samples of the bracket and fascia materials to determine their electrical properties, which are required to run accurate electromagnetic simulations, using either waveguide or quasi-optical techniques. The measured electrical properties include the dielectric constant and loss tangent of the fascia, paint layer and bracket.

Autoliv engineers use a computer-aided design (CAD) file from the automobile’s original equipment manufacturer (OEM) that contains the current geometry of the bracket, fascia and other nearby components. ANSYS SpaceClaim is used to translate and prepare the CAD for HFSS import and meshing improvement. They truncate the fascia in the simulation model to both conserve computational resources and preserve electromagnetic fidelity. Engineers have already created ANSYS HFSS models of all of the company’s current radar systems. They select the radar system to be used on the vehicle and position it within the bracket of the simulation model as an initial design according to Autoliv packaging guidelines. Then engineers assign measured electrical properties of the fascia, paint and bracket to their respective objects within the model. The simulation is run employing ANSYS HFSS, ANSYS HFSS-IE solver and ANSYS High-Performance Computing.



Sensor transmit radiation pattern with fascia

**Autonomous Vehicle Radar: Improving Radar Performance with Simulation**
**ansys.com/av-radar**


Predicted versus measured radar sensor bearing prediction error

## Meeting Accuracy Requirements

The simulation results are then post-processed in HFSS and exported into a custom MATLAB program that mimics the algorithm used by the radar sensor to evaluate radar performance, including signal-to-noise ratio, field of view, bearing bias and bearing ambiguity. It allows engineers to determine, for example, the maximum distance at which the radar can detect an object with a given radar cross section at a given azimuth angle, such as an oncoming motorcycle in the next lane at a distance of 30 meters.

If predicted performance does not meet minimum requirements, geometrical countermeasures are necessary, such as relocating the radar, and then the simulation process repeats. The geometry of the fascia is also likely to change during the design process, but when changes occur, Autoliv engineers obtain the new geometry, run their simulations again and, when necessary, modify their design.

Anechoic room used for fascia materials testing

Integrating a radar sensor into a vehicle so that it will deliver the high levels of accuracy required to meet government regulation and customer expectations is a challenging task. Autoliv engineers have used ANSYS HFSS electromagnetic field simulation software to integrate many radar systems into new vehicles without a single issue that required an additional design iteration. Simulation also has helped engineers identify improvements in packaging design that made it possible to substantially increase the range and accuracy of the radar system.

"Autoliv engineers have used ANSYS HFSS to integrate many radar systems into new vehicles without a single issue that required an additional design iteration."

Radar Road Trip
ansys.com/road-trip

# Autonomy on Roadways and Railways

RPS reads coded paint drop bit patterns on road.

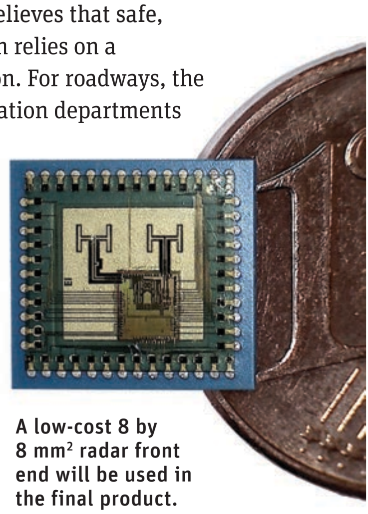
The success of autonomous vehicles depends on both changes in the vehicles themselves and the transportation infrastructure. Autodrive is developing technology that uses plastic code markers on roads and rail tracks to precisely locate a vehicle. Such precision can increase the safety and the traffic capacity of infrastructures and reduce energy consumption on railways. It can also help to avoid automobile collisions and provide a powerful tool to achieve Level 5 autonomous driving. Simulation and model-based development code is critical in creating the certified embedded software that controls the hardware in these systems.

By **Alejandro Badolato**,
Founder and CEO,
Autodrive Solutions,
Madrid, Spain

**Roadway Applications**

Many of the autonomous vehicle solutions being developed today focus on the sensors and embedded software in individual vehicles making the right decision for that vehicle. Slowing down, braking, turning, speeding up — all depend on information being continuously gathered by sensors in the vehicle. Some additional information can be obtained from communications with other vehicles in the area.

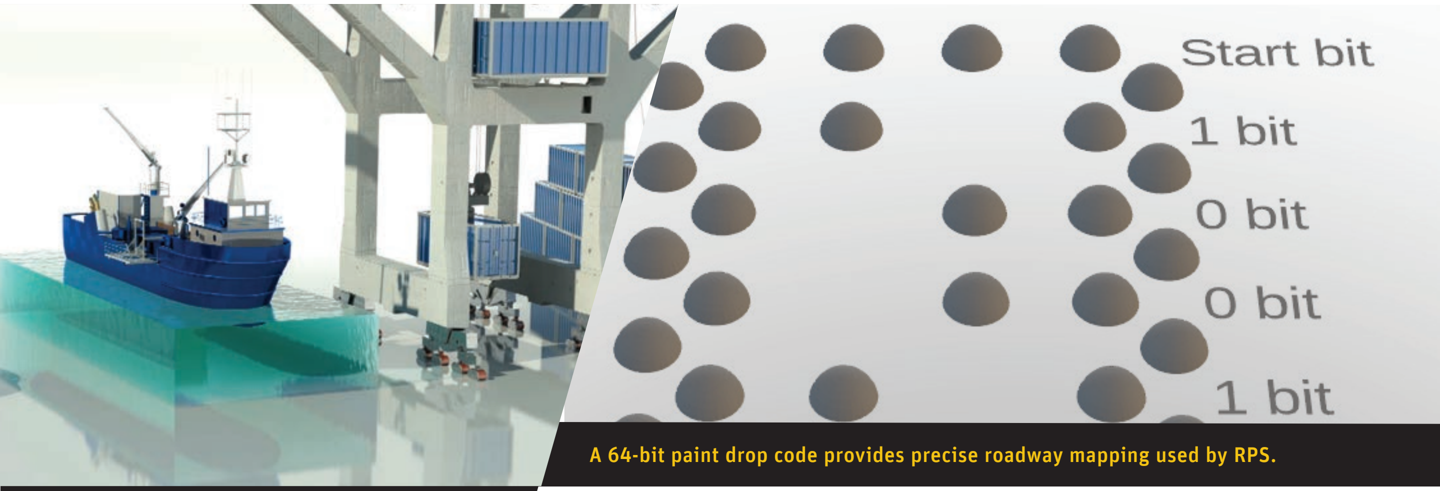
Autodrive Solutions believes that safe, autonomous transportation relies on a coordinated societal solution. For roadways, the cooperation of the transportation departments in cities and states is necessary to establish central host data centers that will act like air traffic control systems. The central host computers will collect data from vehicles on the roads and synchronize traffic flows. This could go as far as eliminating the need for traffic lights.



A low-cost 8 by 8 mm² radar front end will be used in the final product.

To make this possible, every centimeter of every road must be mapped using a unique series of circular, 6-mm-thick plastic paint spots. The paint spots will run down the center of each lane in 64 rows of four spots each to produce a 64-bit digital code that tells the vehicle its location with

**“ANSYS SCADE proved to be absolutely critical to Autodrive engineers, saving the company 80 percent in development time in getting RPS to market.”**



A 64-bit paint drop code provides precise roadway mapping used by RPS.

centimeter precision. This valuable data can be shared with the central host.

A mapping vehicle will drive on every lane of the city when the paint drops are completed. It will log every 64-bit pattern and create a map of each centimeter of the roadway to serve as a reference map. While such precise mapping of every road may seem prohibitively complex and expensive, existing automated line painting trucks could be easily modified to deposit paint drops instead of lines. Autodrive engineers, taking into account data provided by the Los Angeles Department of Transportation, have determined that the entire 44,900 km of driving lanes in Los Angeles could be coded with paint drops in two months by 50 trucks painting at a rate of 6 km/h.

In everyday operation, a radar unit containing four separate millimeter-wave (mm-wave) radar detectors located under an autonomous car will read the four paint spots in each row as the automobile passes over them. This reading is achieved through the mm-wave radar's ability to measure the distance to the ground with 0.1 mm accuracy every 50 µs. In this way, each radar is able to obtain a high-detail profile of the ground while the vehicle is running, detecting the presence or absence of a paint-drop due to its thickness.

After reading the entire 64-bit code, the vehicle is located with 1 centimeter accuracy. The road map stored in the memory of the vehicle will anticipate the road shape ahead and update the position by reading row by row instead of waiting for a complete 64-bit-code read. This is possible because the next 64-bit-code sequence is already known. Therefore, the vehicle can set the optimum trajectory for driving safely using the road shape embedded in the road map.

The extreme accuracy of RPS enables data sharing between vehicles by transferring the vector of each target from one car to another. In this way, the autonomous car can use the information gathered not only by its own sensors but from a vehicle that is driving 100 m ahead, improving the vehicle's perception. It will also transmit its location to the central host traffic controller, which will use the information from all vehicles to control the flow of traffic in that region.

### The Radar Position System

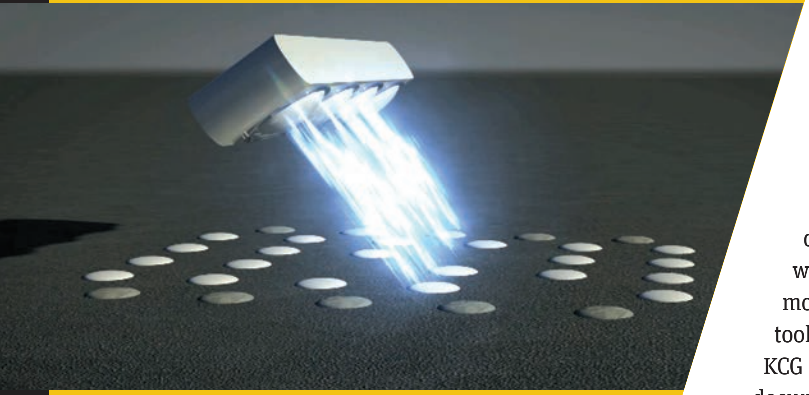
Autodrive's Radar Position System (RPS) uses the miniaturized, low-cost, high-resolution mm-wave radar sensor developed by the European Union's SUCCESS consortium in its radar units. The surface-mountable package of this fully integrated 122 GHz radar sensor is 8 mm by 8 mm and includes an SiGe chip along with transmitting and receiving antennas. Four of these sensors are housed in sealed, weatherproof plastic units connected to the chassis under an autonomous vehicle. The system is absolutely secure — it is

Installed Antenna Performance
ansys.com/installed-antenna

> "Continual speed adjustments could result in a ***savings of 20 percent*** of the ***8 billion*** euro energy cost of the European train fleet each year."

impossible to jam the radar because it has a very high frequency of 122 GHz and a huge bandwidth of more than 15 GHz. Any manipulation of the track is easily detected as it will generate a mismatch with the recorded road map.

A customized plastic lens had to be developed to focus the radar waves into a 1-cm circle over the ground to achieve the 1-cm positioning accuracy of the RPS. Autodrive engineers used ANSYS HFSS SBR+ — the industry-leading tool for simulating installed antenna performance on electrically large platforms, including the applications of predicting installed radiation patterns, field distributions and antenna-to-antenna coupling — to successfully design the lens.



**Four-radar RPS reading paint dot bit pattern on road**

Due to a small wavelength (lambda less than 3 mm) and a big simulation volume (100 lambda by 100 lambda by 400 lambda), the problem has to be divided for optimizing computing requirements. A first simulation of the patch antennas is obtained using the finite element method solver from ANSYS HFSS. Then the simulation results are used to excite the radiating source in HFSS SBR+, which leverages the asymptotic Shooting and Bouncing Ray Plus (SBR+) technique to efficiently compute accurate solutions.

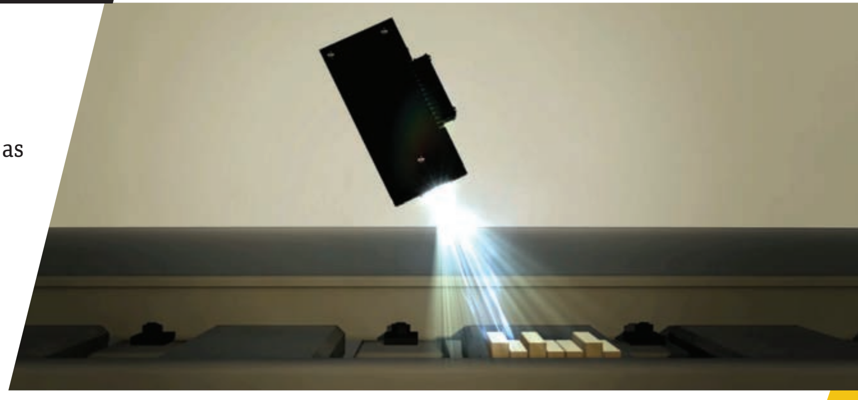
The lens was essential to the operation of the RPS, but perhaps even more critical was the development of the embedded software that must control the hardware flawlessly to meet the EU's rigid certification standards. While Autodrive Solutions had a lot of experience with radar systems, they had little with critical real-time embedded software. So they turned to ANSYS SCADE to generate, validate and obtain certification for their software.

SCADE proved to be absolutely critical to Autodrive engineers working on this application, saving the company 80 percent in development time in getting RPS to market. The engineers focused on the model, on solving the problem, and let SCADE develop certifiable software to control the hardware they developed. If they found after testing that there was a problem with the model, they simply had to modify the model to solve the problem. SCADE then took this model to generate the code with the certified KCG compiler to provide the traceability and the documentation required by the certification authorities in a few minutes. SCADE-generated software met the certification standards for embedded software in critical safety applications every time.

### Railway Applications

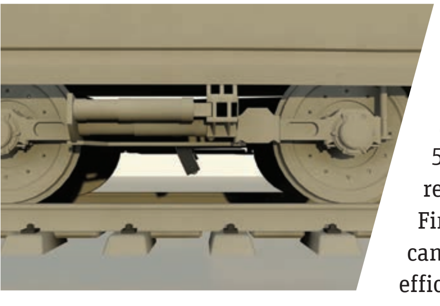
Though it seems less obvious, the railway industry also has challenges that can be solved using autonomous systems. Determining the precise location of a train on a track is not as easy as it might seem. Because of this, the cost of stopping a train accurately, which is required for deploying platform screen doors (to prevent people from falling or jumping onto the tracks), is 0.5 million euros per train station. With the current technology, when a train passes an RFID unit, a preprogrammed braking process is automatically initialized. This process can estimate where the train will stop. The high cost of stopping a train accurately is due to the continuous calibrations required for each train because the braking process depends on multiples variables such as the number of coaches, the load, the wear of the wheels and so on.

Autodrive Solutions developed a solution similar to the one they created for roadways. In this case, instead of dots of paint, they install bars of plastic either 1-cm or 2-cm high in a cluster at multiple points along the train tracks. A 1-cm-high bar represents a digital 0, and a 2-cm-high bar represents a digital 1. A cluster of these bars can therefore encode the location of the train on the track in a series of digital bits that can be read by a single RPS unit attached to the bottom of the train's engine car. By measuring the time it takes for the train to travel between specific locations, they can determine precisely how fast the train is traveling at each point and apply a customized braking process tailored to the load of the train. The adaptive braking system gives operators precise control over where the train will come to a stop.



Single RPS railway unit reading height of plastic bars on train tracks

RPS can also increase the amount of traffic that can be safely handled on a given railway by reducing the headway — the distance separating two consecutive trains. In Europe today, a track is divided into segments called "block sections" that have a minimum length of 400 meters; if one train is in a segment, no other train can enter that segment. This 400-meter separation, which is designed for safety, produces bottlenecks that limit the number of trains traveling through an area. The bottlenecks occur most frequently near train stations and cities, where trains run at slow speeds.



Single RPS unit under train

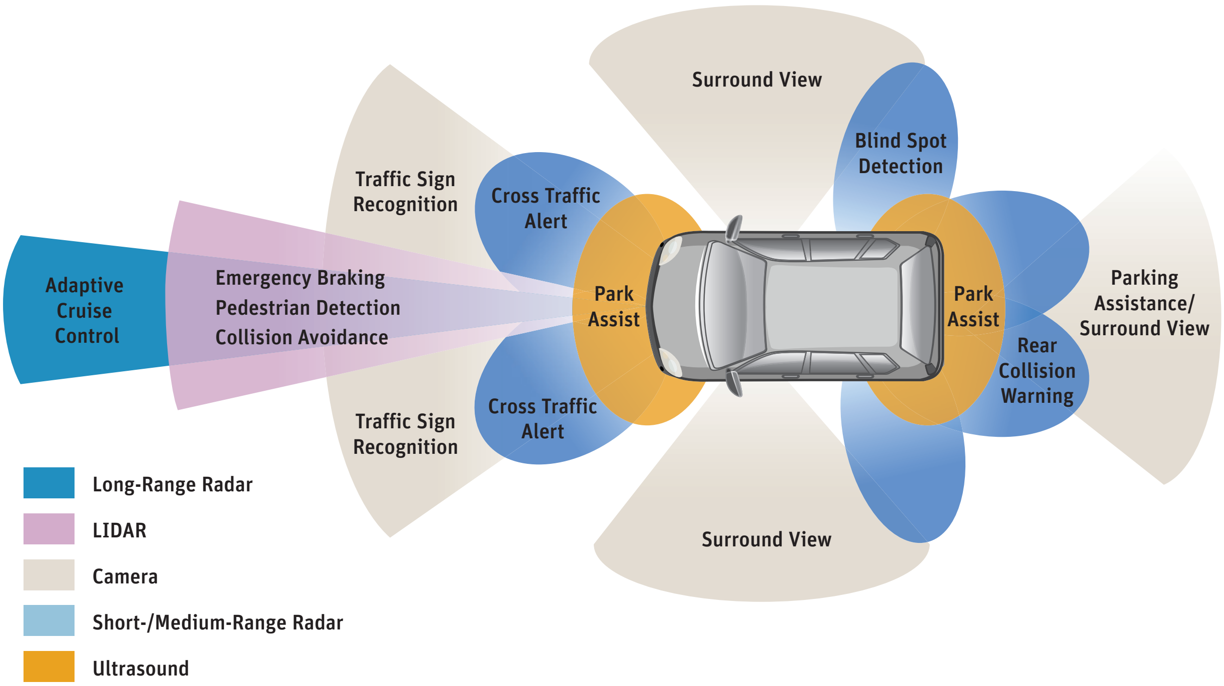
Autodrive's accurate positioning RPS can reduce the headway by reducing the block section length to only 50 meters, significantly reducing bottlenecks. Finally, Autodrive's RPS can also increase the energy efficiency of train systems. Today, European trains travel between two consecutive RFID beacons at a fixed speed. When the train detects a signal indicating it can speed up or slow down in the next segment, it does so. The RPS can detect when track conditions change at smaller intervals. It can tell if the slope is uphill or downhill and adjust the speed for these conditions immediately, without waiting for a signal in the next Eurobalise (European Standard RFID signaling device). Continual speed adjustments could result in a savings of 20 percent of the 8 billion euro energy cost of the European fleet each year.

Autodrive has successfully tested a prototype of the RPS in Metro de Madrid. They have also tested the measuring capabilities of the radar in a high-speed train traveling at 330 km per hour.

Using embedded software generated by ANSYS SCADE, Autodrive expects to achieve the SIL4 (Safety Integrity Level 4) certification as specified in standard EN 50128 during 2018, which will allow them to sell their technology on the European railway market soon.

### Future Plans

Autodrive Solutions' RPS has possible future applications for aircraft that are taxiing on a runway and for optimizing the speed and braking of the Hyperloop. They are collaborating with departments of transportation, as well as metro and train authorities, in various cities around the world to explore the possibility of using the RPS to improve roadway and railway transportation safety and efficiency. ANSYS SCADE and ANSYS HFSS SBR+ simulations will be part of every solution they develop throughout the world.




# Autonomous Vehicle Radar:

## Improving Radar Performance with Simulation

Radar systems provide important sensor input for safe and reliable autonomous vehicle operations. Ensuring that these radar systems operate without interference, cover the intended areas, do not fail from installation effects and provide accurate input to the control system requires use of advanced engineering simulation.

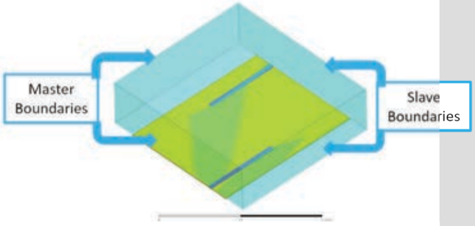
By **Shawn Carpenter,**
Product Manager,
High Frequency Electronics,
ANSYS

Autonomous vehicles require the continued evolution of vehicle sensors — the eyes and ears of the control system that perceive the operational characteristics of the vehicle and the environment around it. The sensors feed the vehicle control systems with data on the current and developing state of the vehicle's surroundings. Both operation and safety depend on the accuracy of the sensor system.

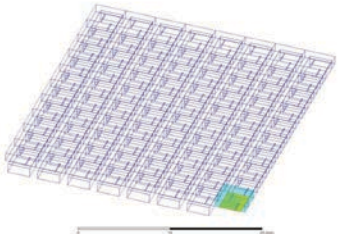
Four major classes of vehicular sensors provide the lion's share of environment sensory data for an autonomous vehicle — visual spectrum cameras, laser-ranging devices (lidars), ultrasound sensors and radio frequency ranging sensors (radar). Automotive radar employs millimeter-wave frequencies for long-range object and obstacle detection, as well as for tracking the velocity and direction of the various actors such as pedestrians, other vehicles, guardrails, etc., in the environment around the vehicle.

## SIMULATION OF A RADAR ANTENNA

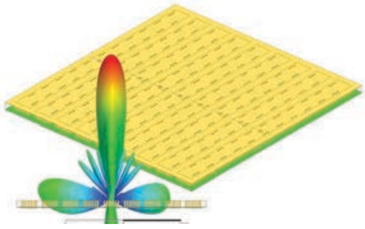
This example illustrates the development of a 77 GHz automotive radar sensor based upon a two-sided printed circuit board (PCB) fabrication technique using a slotted waveguide.



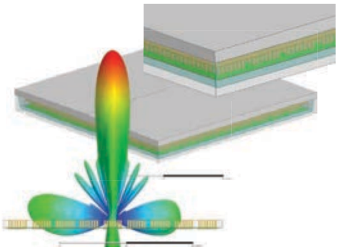

ANSYS HFSS is used to quickly optimize proper dimensions for each element of a slotted waveguide unit cell in an extended antenna array.



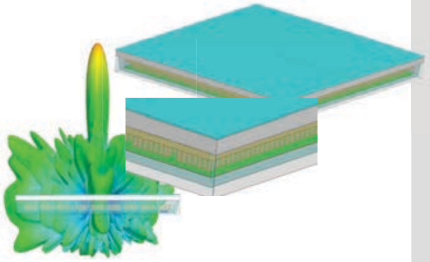
Once the design of the unit radiation cell is optimized for the desired frequency, a full-size array can be laid out quickly and automatically. Simulations are run with an automated and highly scalable technique to determine the minimum number of cells required to achieve spatial radiation coverage and the efficiency with which the array radiates power.



When an array design satisfies performance requirements, the fabrication details (vias, metal thicknesses, structures to couple power into the waveguides, etc.) can be added to simulate realistic materials and manufacturing processes. A digital exploration design of experiments (DoE) can be run against the expected fabrication process tolerances to assess the manufacturing yield of this array. This initial design of the array with vias, PCB filler and transitions shows a simulated far-field radiation pattern when all the array elements are fed with power.



The effects of the packaging and housing can be investigated to understand their influence on the sensor's performance. Metal in and near the packaging can create electromagnetic coupling to the array that might degrade its ability to radiate to specification. Proximity effects of the radome and other nonmetallic packaging can also have an impact. These effects can be determined and even remediated in a simulation model prior to building a physical prototype.



Environmental effects on the packaged sensor's performance can also be considered, such as rain, ice, dust or other materials. In this simulation, a thin layer (0.1 mm) of water or ice is studied over the radar package, showing that the water has minimal effect on the main beam gain, but increases the sidelobe level by another 4 dB. By understanding performance under different environmental conditions, engineers can optimize the array's design and build appropriate margins into the original design.

*"For automakers to gain the full benefits from automotive radar technology they must judiciously use simulation to meet development schedules and to achieve performance requirements."*

Three major classes of radar systems are typically employed in automotive active safety systems:

- Short-range radar (SRR) for collision proximity warning and safety, and to support limited parking assist features.
- Medium-range radar (MRR) to watch the corners of the vehicle, perform blind spot detection, observe other-vehicle lane crossover and avoid side/corner collisions.
- Long-range radar (LRR) for forward-looking sensors, adaptive cruise control (ACC) and early collision detection functions.

Today's automotive radars incorporate technology that 20 years ago could only be found in advanced research in aerospace and defense laboratories. For automakers to gain the full benefits of this technology — including chip-level integration, package and sensor miniaturization, fewer parts, lower power consumption, and higher performance, all at dramatically lower costs — they must judiciously use modeling and simulation to meet aggressive development schedules and achieve challenging performance requirements.

Radar simulation can be employed to design single radar components (antenna and array), develop a system including all radar installations and the vehicle, or even extend to a virtual system of multiple radar systems, the vehicle itself and its environment — a digital prototype.

**Rapid Development of Radar Sensors**

High-performance radar design starts with the antenna — the interface between the sensor and the world that it is sensing. Ideally, these antenna systems must concentrate energy in one direction over a defined coverage angle. Antennas must radiate efficiently so that energy is not dissipated in the antennas themselves or in the sensor package materials. Energy should not be lost due to poor match with the transmit power amplifiers.

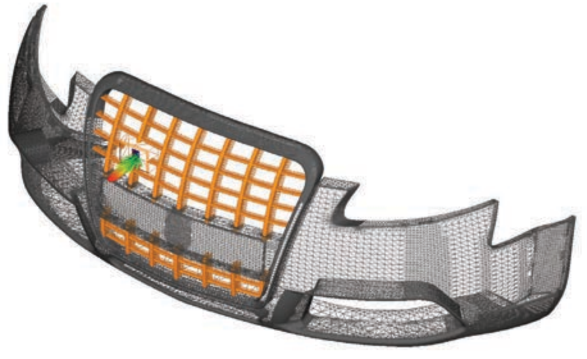
High-frequency modeling and simulation present tremendous opportunities for time and cost savings in the design and development of radar sensors. With simulation, engineers can:

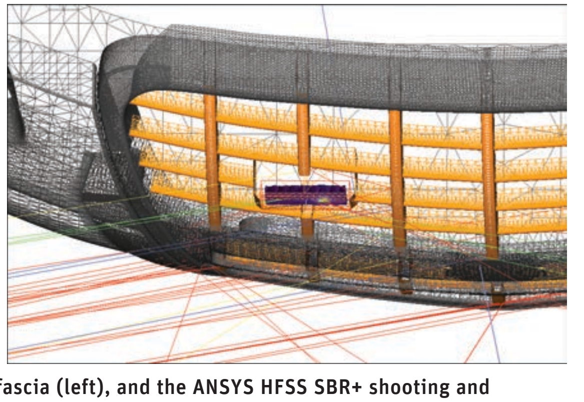
- Virtually prototype and "tune" antenna topologies quickly, without requiring fabrication.
- Test antenna variants effectively and efficiently to understand their behavior under a variety of structural and environmental conditions.
- Optimize element and multichannel antenna arrays with the least effort and cost.
- Build only a single prototype to test at the end.

**Integrating the Radar with the Vehicle**

Once a sensor design or prototype is developed, it must be evaluated as installed on a vehicle. Many

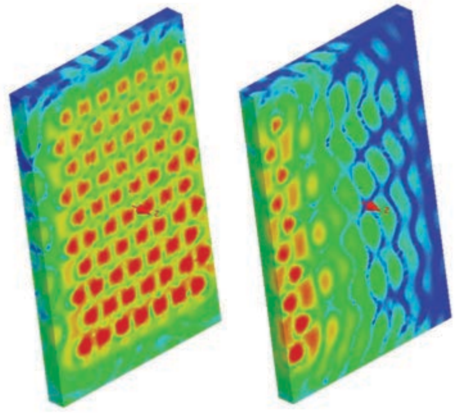
**Radar Simulation of a Busy Intersection**
**youtu.be/v2sJKa3vjEg**



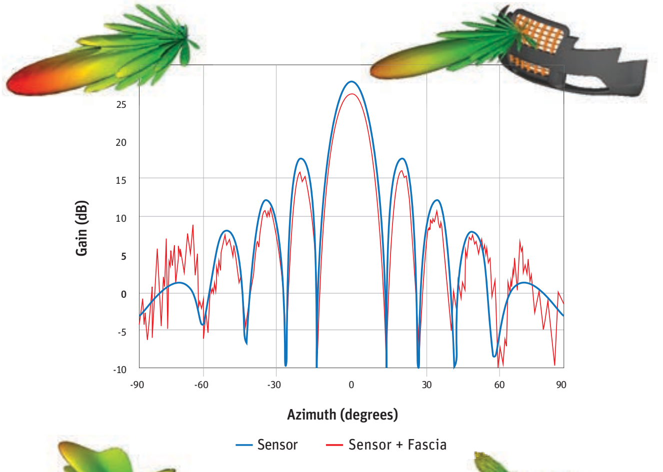


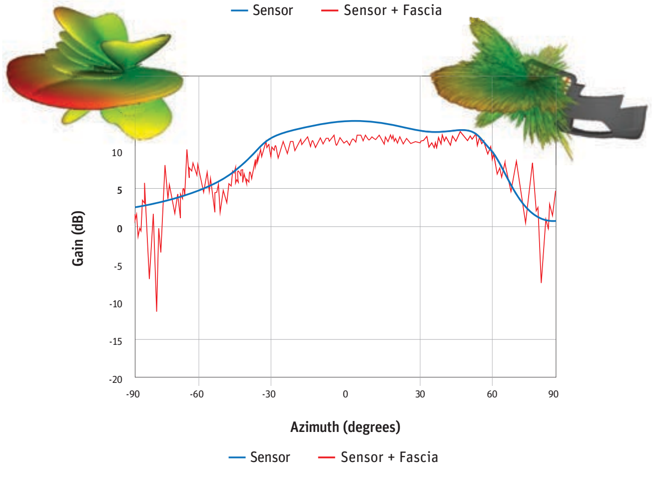
A radar sensor array model is installed in a proposed automobile fascia (left), and the ANSYS HFSS SBR+ shooting and bouncing rays EM field solver is applied to model the installation interactions. The HFSS finite-element simulation for the radar sensor antenna system is shown in the proper installation location, and a subset of rays employed by the HFSS SBR+ simulation is shown at an exit angle of 80 degrees.

> *"Radar systems play a central role in safety systems and must be tested with vehicle control systems and algorithms to validate safe operation."*



ANSYS HFSS–simulated near-fields surrounding sensor for Tx channel (left) and for Rx channel (right) form the basis for excitation in the HFSS SBR+ fascia interaction solution.




Receive channel subarray radiation pattern (top) and transmit channel radiation pattern (bottom) show radiation patterns for the module in isolation, and as installed to include fascia and bumper interaction.

radar sensors are mounted either behind a bumper or in the vehicle fascia. The proximity effects of the vehicle design can affect the performance of the radar — particularly the antenna's ability to focus radar energy. The vehicle manufacturer develops bumper and fascia designs to be both aerodynamic and aesthetically pleasing to their buyers. The unique features of a body shape that meet aesthetic goals could negatively impact the performance of a radar sensor integrated into it or hidden behind it.

In the past, the effects of radar-to-fascia and radar-to-bumper interaction were evaluated through cooperation between the sensor manufacturer and the vehicle manufacturer. This was an iterative process based on trial-and-error prototyping. Valuable development time and cost were invested in prototypes that required retooling as the car was redesigned.

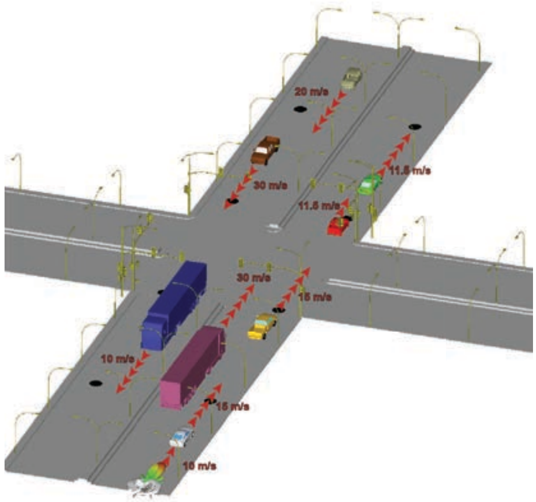
Modeling and simulation reduces this process from as long as nine months to a matter of days. ANSYS HFSS SBR+ can integrate models, including highly accurate results from finite element ANSYS HFSS models, for the isolated sensor system, and simulate its interaction with the much larger fascia and bumper using its high-frequency ray tracing methods. The simulated installed radar antenna response shows the radar engineer how each radar subarray will illuminate the road or environment when it is installed into the proposed fascia–bumper design.

### Virtual Road Testing for Radar

Autonomous vehicle developers are devoted to the safety of passengers. Radar systems play a central role in safety systems and must be tested with vehicle control systems and algorithms to validate safe operation. Without the benefit of modeling and simulation, this would require driving millions of test miles. Today, most AV developers are moving this process to the domain of the digital prototype. In modeling and simulation, testing can be performed for any conceivable scenario.

However, high-fidelity modeling of the electromagnetic performance of an automotive radar system has to this point proven to be a major challenge.

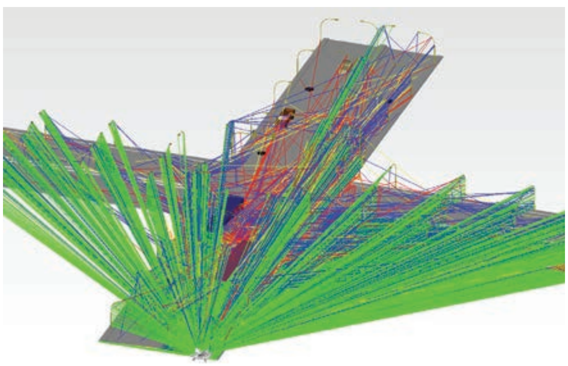
**Solve Large-Scale Problems in a Connected World**
ansys.com/large-scale



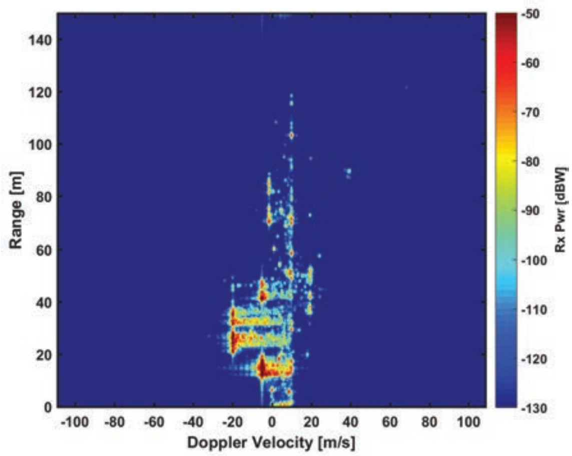

**Busy intersection environment geometry. Velocity of each moving actor in the scene is shown.**

Full-physics modeling and simulation of radar sensors creates an enormous EM analysis problem as the radar needs to cover an area that could occupy over 1.4 million electrical wavelengths. This is compounded by system-level requirements that include the number of times the central control system is updated by radar, the number of antennas involved, the range and velocity resolution of the MRR system, and the comparative velocity of the environmental actors.

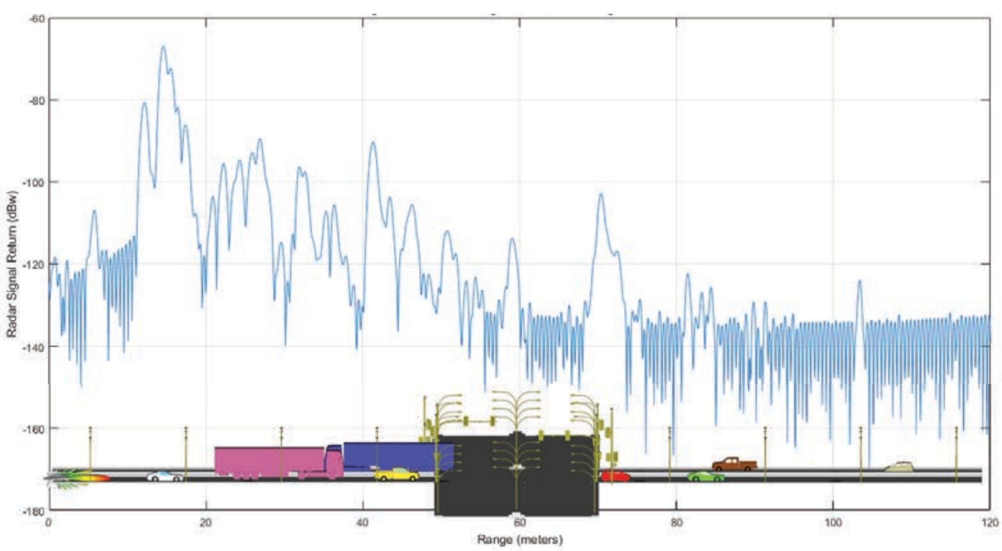
While these considerations pose challenges to high-fidelity EM modeling of radar–environment interaction, they are not insurmountable. An appropriate application of the shooting and bouncing rays (SBR) technique using ANSYS HFSS SBR+ can



**Shooting and bouncing rays traced from radar transmit channel throughout the environment. Multiple colors correspond to ordinal reflection for each ray track pictured.**




**Range-Doppler map for radar system over a radar frame of 200 consecutive 300 MHz pulses**




**Range profile for a single radar 300 MHz bandwidth pulse with 0.5 m resolution. Radar is visible in overlay at lower left. The range profile shows distance of flight for all radar echoes received by the radar system in response to the modeled environment. Very strong radar returns for some light posts, the surfaces of several of the vehicles, and between vehicle reflections are shown. The signals are stronger from closer targets than from more distant targets, but even targets well down the road are detectable. Due to the waveform's resolution, the radar may detect multiple target echoes from the same vehicle.**

provide full-physics simulation of such problems with good accuracy and reasonable efficiency — in terms of both computer resources and modeling time.

ANSYS HFSS SBR+ can be used to synthetically reproduce the signals obtained by a high-fidelity radar model. Any specified bandwidth may be applied to the simulation to foster virtual innovation by enabling the engineer to test new waveforms that may not be currently available from sensor suppliers.

Radar signal processing systems need to intelligently group distributed target returns that belong to the same actor in the environment, or the vehicle control system will be overwhelmed with too many targets to track. This grouping is made possible by processing the possible Doppler-shift of the signals that bounce off surfaces with a velocity that is different from the observation domain. Radar signals from targets that have the same velocity in consecutive range bins can be considered to be from the same target. Accurate determination of targets in terms of both range and velocity requires a large number of pulses to be analyzed over time. ANSYS SBR+ results make it possible to develop Range-Doppler maps that show the range to the target returns on one axis and the extracted velocity of the targets on the other.

A typical automotive radar sensor provides updates to the vehicle control and safety systems at a rate of 5 to 30 frames per second. The speed and accuracy of ANSYS HFSS SBR+ allows a complete simulation of the movement of vehicles through this environment to develop a Range-Doppler map over time for the scene. Placing the HFSS SBR+ simulation within the simulation loop of a complete autonomous vehicle creates a digital prototype to test the vehicle control system or active safety system.

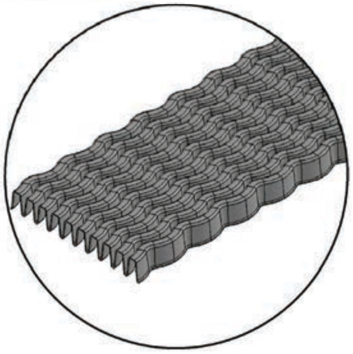
**Complete Modeling and Simulation Work Flows**

Radar sensor developers, automotive OEMs, active safety systems developers and autonomous vehicle control systems developers use ANSYS solutions to design radar sensor modules, study their installed performance on the vehicle, and gain insight into radar reports for moving and stationary targets on a full, dynamic road scene. From a single component to a digital system prototype, ANSYS provides unique solutions for this very challenging high-frequency problem.

**Autonomous Vehicle Radar: Improving Radar Performance with Simulation**
ansys.com/av-radar

# Simulation and Additive Manufacturing Speed Tooling Design

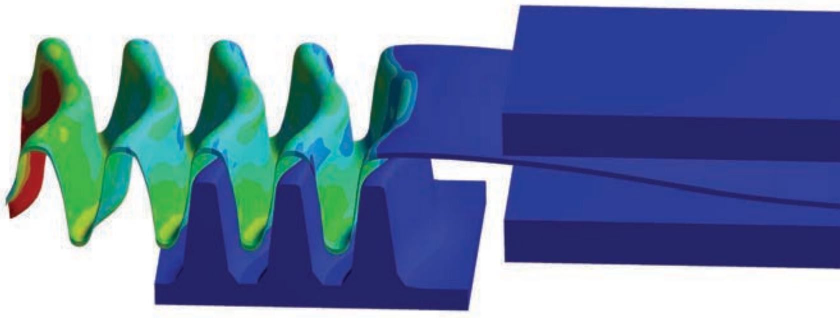
By **Mark Davey**,
Principal Engineer,
Senior Flexonics Inc.,
Bartlett, USA



The first step in the manufacturing process is to stamp fins into a flat pattern.

When tooling suppliers told Senior Flexonics engineers that considerable troubleshooting and cost would be required to validate tooling to manufacture finned tubes for a new compact liquid/air heat exchanger, they turned to ANSYS software. Employing ANSYS LS-DYNA to simulate the stamping operation allowed them to design a progressive die prototype right the first time. They were able to produce the tool at a 95 percent lower cost and in 75 percent less time than the best supplier quote.

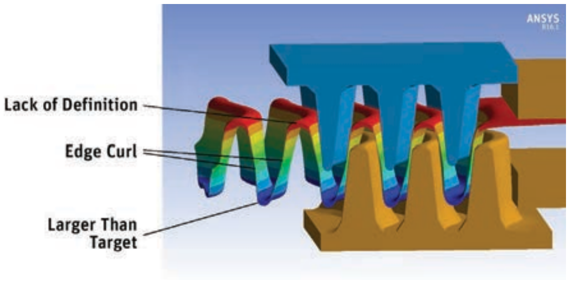
**SENIOR FLEXONICS** is developing a next-generation compact liquid/air heat exchanger (HEX) for multiple industrial and mobile applications. By using finned tubes to increase the heat transfer between the hot gas in the tubes and the cold water in the shell, the new HEX is smaller and lighter than current models. However, these finned tubes are challenging to manufacture because the high height-to-width ratio of the fins makes stamping difficult due to very high stresses and strains on both the raw sheet and the progressive die. When the company took this new design to its two tooling suppliers, one said they could not do it and the other said it would take 12 weeks and cost $60,000 because a lengthy trial-and-error process on the shop floor would be required to make a reliable tool. Senior Flexonics engineers decided to simulate the stamping operation using ANSYS LS-DYNA explicit dynamics software to speed the tool prototyping process. Simulation made it possible to identify and correct problems in an existing original progressive die design, select the right part material and validate the process of bending the finned sheets into a cylinder. Using additive manufacturing (3D printing), tooling developed employing simulation arrived in only three weeks, at a cost of $3,000, and worked perfectly the first time.



Simulation guided engineers in developing a new progressive die that produces good fins.

## New-Generation HEX

Senior Flexonics produces industrial heat exchangers, as well as EGR coolers for heavy-, medium- and light-duty trucks, high-pressure diesel fuel tubes and rails, water tubes, turbo oil drain lines, metal bellows, piston cooling jets, and complex assemblies. The company's engineers designed its newest HEX to increase heat conduction between the hot and cold fluids so that the cooler was smaller and lighter, both important advantages in the automotive and trucking markets. To do this, they designed longitudinal fins within the tubes that increase the contact area between the hot gas in the tubes and the cold liquid in the shell of the heat exchanger.




Simulation identified problems with fins produced by existing progressive die design.

When Senior Flexonics engineers asked their tooling suppliers for quotes to build the progressive die tooling needed to manufacture the fins, the suppliers pointed out that the depth of the fins forced the stainless steel material to the edge of its formability limits. They said it would be very difficult to predict in advance a tooling geometry that would provide the correct final shape. They were also concerned about tearing in high-stress areas. They expected that a trial-and-error process would be required to meet the design specifications.

## Simulating the Stamping Operation

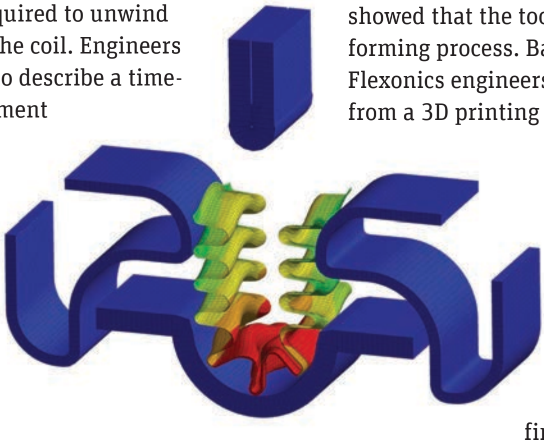
Senior Flexonics engineers decided to design the tool internally and to contract a 3D printing service bureau to build it. The engineers were not familiar with ANSYS LS-DYNA, but they were able to quickly and easily set up the simulation due to their familiarity with the ANSYS Workbench environment. They extracted an initial tool design in CAD software and opened the CAD model in Workbench. Engineers generated the finite element mesh in Workbench using the automatic multizone method. They modeled

Additive Manufacturing and Topology Optimization
ansys.com/additive-topology


**Printed tooling installed in stamping press**

the tool as 17-4 PH stainless steel solid elements and the raw material as 400-series stainless steel shell elements. The model included 64,230 nodes and 67,112 elements. To model a strip of material pulled out of a feed chute they used a friction element to apply forces to mimic those required to unwind and pretension the strip from the coil. Engineers wrote a user-defined function to describe a time-dependent sinusoidal displacement function that provides gradual startup and slowdown on each stroke of the die to ensure a stable solution.

ANSYS LS-DYNA iterated to a transient solution of four stamping cycles in 38 hours. The simulation displacement results showed that the part produced by an existing initial tool design would have curled at its crown and walls where it was supposed to be relatively flat, and that the radius at the root of the fin was too large. The strip-forming strain results showed considerable tearing. Based on the simulation results, Senior Flexonics engineers adjusted the tool geometry to counteract the distortion problems. They changed the material to 316L stainless steel to address the tearing problem. After only a couple of iterations, the simulation predicted that the new progressive die design would produce parts of the right geometry and limit tearing to just the first fin on the strip, which was acceptable. The tooling stress results showed that the tooling could easily withstand the forming process. Based on these results, Senior Flexonics engineers ordered the prototype tool from a 3D printing service bureau.

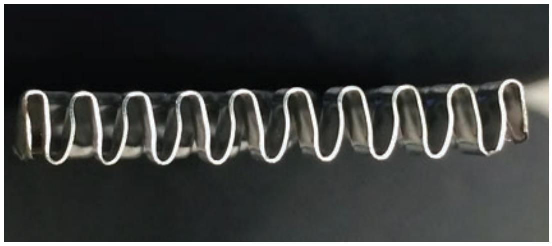


**Compression bending did not properly seal tubes.**

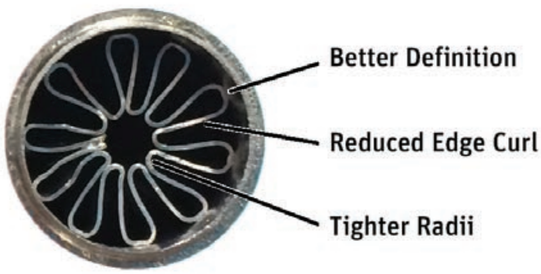
### Simulating the Tube Forming Operation

While they waited for the progressive die to be delivered, Senior Flexonics engineers turned their attention to developing a process to form the finned strip into a cylinder for insertion into a tube. They first used LS-DYNA to simulate a compression bending technique. The simulation results showed that this approach would not bring the ends of the fins together to form a full cylinder. Next, they simulated a tangential wiping system, but this method also did not fully close off the cylinder. Finally, they simulated a rolling process that provided considerably better results but still did not quite fully form the cylinder. Engineers modified the rolling die design, decreasing the diameter at the outlet so that the rolled cylinder popped out of the tool for spring-back insertion into a tube. Simulation showed that this approach provided a tight seam, so the rolling die was also procured from a 3D printing service bureau.

When the prototype progressive die was received, Senior Flexonics engineers installed it in a stamping press and ran a short strip. The results closely matched the simulation predictions and met all design specifications. The rolling die also matched the simulation by working correctly the first time. Without simulation, the chances are that both the progressive die and the rolling die would have required expensive repairs and possibly even rebuilding to resolve the problems that were identified in simulation. Simulation made it possible to obtain appropriate dies on first delivery, which saved tens of thousands of dollars and enabled the company to meet the product development schedule. Λ



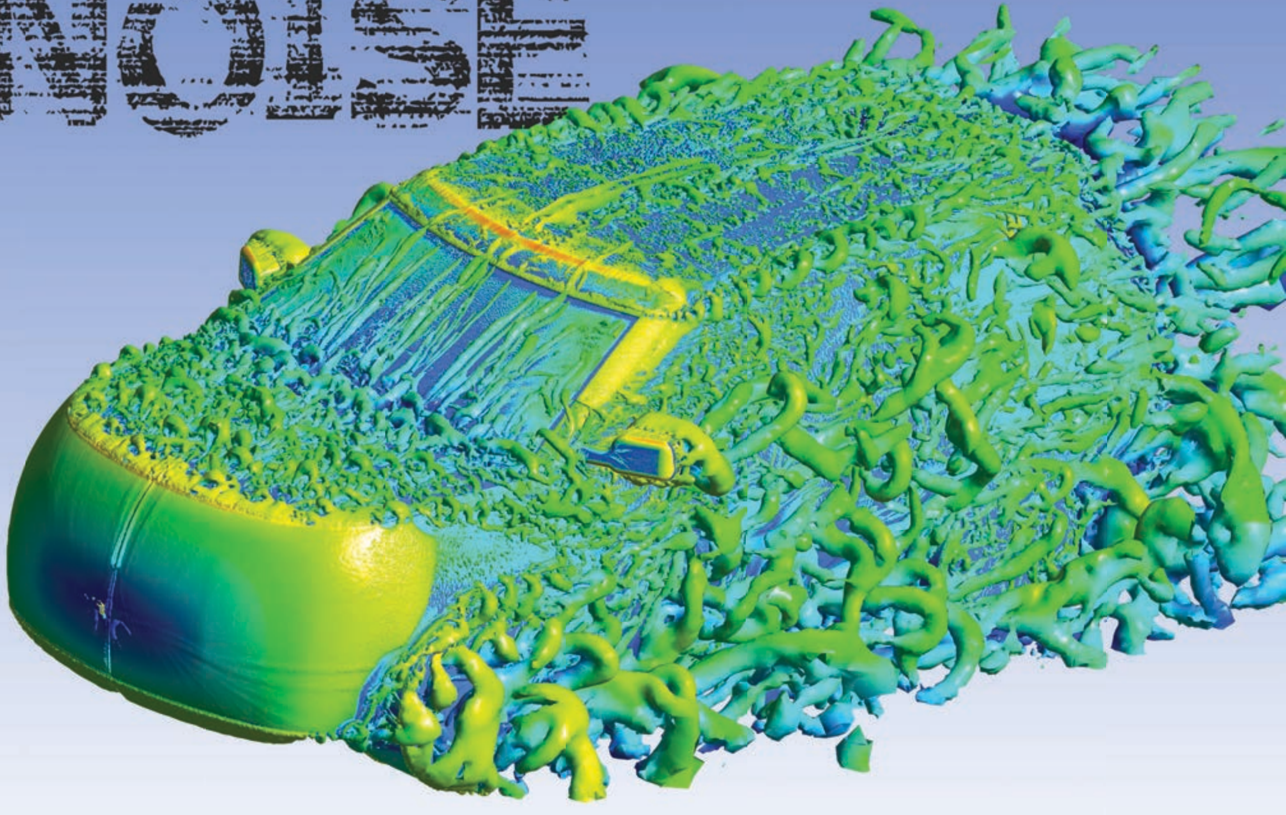
**First fins produced on existing tool matched simulation predictions.**




**Second fins produced on optimized 3D printed tool matched revised simulation predictions.**

**Second-generation rolling die correctly seals tubes.**

# A WINDOW INTO AUTOMOTIVE NOISE

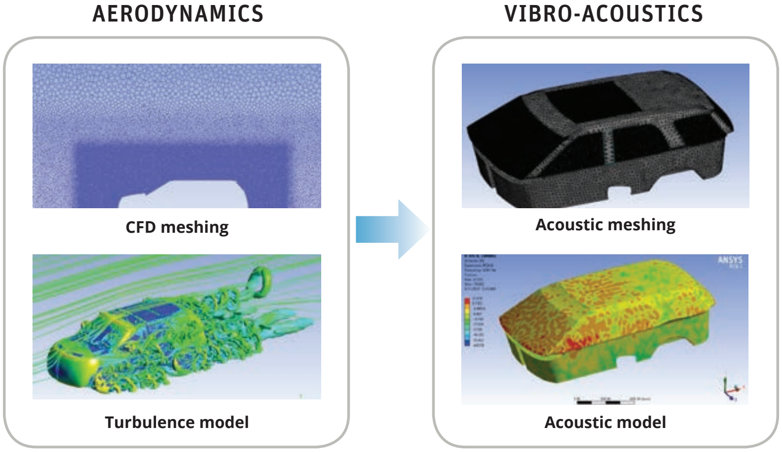


The interior of a vehicle can be distractingly loud due to wind turbulence, especially at highway speeds. At Corning, engineers combined aerodynamic and vibro-acoustic analysis in ANSYS Workbench to determine how glazing can help control interior noise.

By **Chao Yu**,
Senior Project Engineer,
Advanced Machine Systems,
Corning Incorporated,
Corning, USA

Most drivers understand that they have to turn up the radio on the highway if they want to hear their favorite station, or speak louder if they want to have a conversation with their passengers. This is the direct result of the turbulent air flowing around their vehicle when driving at high speed. Recent studies by J.D. Power on U.S. vehicle dependability [1] have reported that excessive wind noise was one of the top problems most commonly experienced by vehicle owners. Depending on where the exterior noise falls in the frequency spectrum, vehicle occupants may perceive that noise as falling anywhere between a quiet conversation (40 to 50 decibels, or dB) and a busy city street (70 to 80 dB).

To help mitigate this problem, engineers at Corning [2] have been studying the physical mechanism by which exterior wind translates into cabin noise. At highway speeds, the air surrounding a vehicle is disturbed by the vehicle's front end, the A-pillar (windshield support structure) and side mirrors. This results in turbulent flow that causes fluctuations in the air pressure field on the outer surface of the vehicle. These pressure variations cause the glazing (windshield and other window glass) to vibrate, which in turn excites the cabin air and generates some of the interior noise. Another major cause of interior noise is the wind on the rest of the automobile surfaces being transmitted through the automobile parts to the cabin (flanking noise). In addition, the sound generated by tires in contact with the road and by the operation of the automobile's mechanical systems contributes to cabin noise.



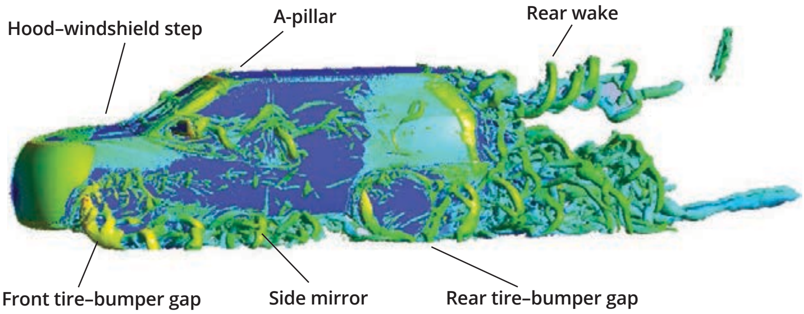

**Full-vehicle wind noise model illustrates the combination of aerodynamic modeling with vibro-acoustic modeling used in the DAVA method.**

Corning engineers wanted to determine which glass surfaces were the most important paths for glazing noise transmission, and also whether lighter-weight glass material would have an impact. The team employed a simulation method called deterministic aero-vibroacoustics (DAVA) using fluid and structural analysis tools in ANSYS Workbench. The DAVA process began with a simplified geometry of a common U.S. sport-utility vehicle to reduce the cost of meshing and overall computation. Because the study focused on sound transmission through glazing, detailed vehicle features in the regions surrounding the glass — such as mirrors and the A-pillar — were maintained, while areas around the bumpers and tires were modeled with less detail. Taking advantage of symmetry, the engineers used ANSYS CFD meshing capability to create a computational fluid dynamics (CFD) mesh of 55 million hexcore cells to model the fluid domain surrounding half of the vehicle geometry. The size of the domain was chosen so that vortex shedding, flow separation and reattachment phenomena could be captured.

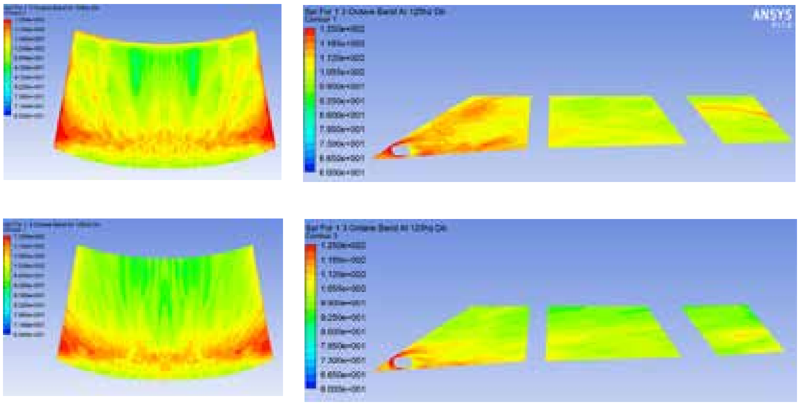
"There was excellent agreement between the simulation results and experimental SPL data."

**Noise Generation**

Once the mesh was complete, Corning's engineering team used the ANSYS Fluent CFD solver to simulate the transient turbulent flow in the domain. To predict the vortices generated by 80 mph air flow over the vehicle, the engineers chose to use the detached eddy simulation (DES) model. DES is a hybrid formulation that switches between the standard Reynolds-averaged Navier-Stokes (RANS) solution and large eddy simulation (LES) modeling based on the mesh resolution and distance from the wall. LES is computationally more expensive, and was used in the coarser domain away from the vehicle, while RANS was used to solve the more finely resolved areas at the wall boundaries. The team ran the DES model for 10,000 time steps to simulate




**Main vortex shedding regions from the turbulent flow field using the Q-criterion, colored by velocity magnitude**



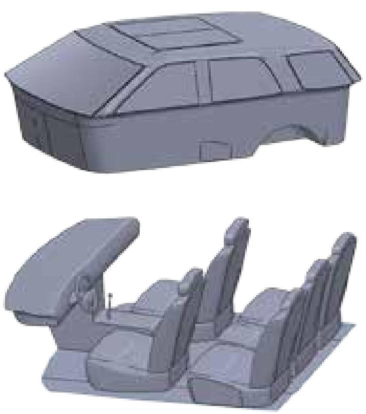
Contours of exterior SPL at 125 Hz on the windshield (left) and side windows (right) for standard transition (top) and smooth transition (bottom). The standard transition shows locally higher SPL values on the sides of the windshield and front side windows.

0.5 seconds of actual turbulent flow. Such a small time step was required because the team needed to resolve frequencies up to 5 kHz to cover the wide range of airborne noise. Corning converted the transient data from the time domain to the frequency domain using the fast Fourier transform (FFT) capability, which allowed them to evaluate the sound pressure levels (SPL) of glazing in the more commonly understood dB scale. This large case required use of ANSYS HPC on Corning's HPC cluster.

The initial CFD analysis showed greater exterior SPL values at the lower corners of the windshield and on the front side windows when compared to the rest of the glazing. In a standard windshield design, there is usually a small under-flushing discontinuity between the glass surface and the A-pillar where the edge of the glass extends under the pillar. The team's baseline vehicle model considered a design with 5 millimeters of under-flush, which they compared to a modified

> "Corning engineers wanted to determine which glass surfaces were the most important paths for glazing noise transmission, and also whether lighter-weight glass material would have an impact."

design with a smooth transition (no under-flush) between the windshield and A-pillar. The modified design predictions indicated an exterior noise reduction of up to 5 dB on the front side windows. In addition to the modified geometry, the team ran the simulation twice more at air flow speeds of 60 mph and 30 mph. As expected, the predicted exterior wind noise was reduced as vehicle speed decreased.



Interior cabin geometry (top) and structures (bottom)

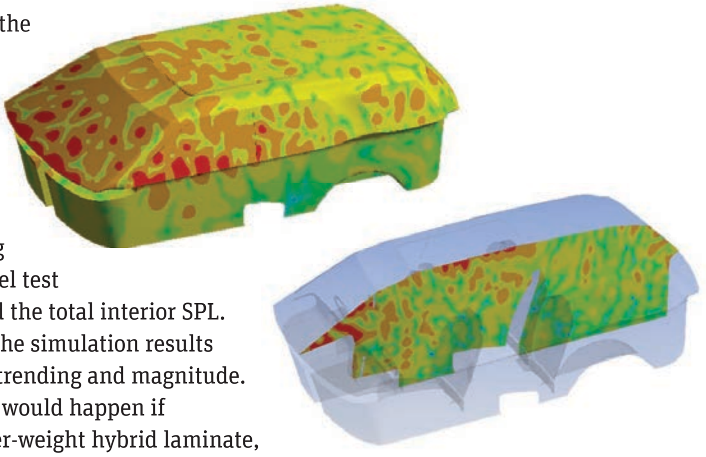
**Noise Transmission and Propagation**

With the exterior SPL predictions in hand, the Corning team used them as inputs in ANSYS Mechanical for the vibro-acoustics analysis. The engineers mapped the pressure onto surfaces of the vehicle body to act as external excitations. The team created a separate mesh for the cabin boundary and interior, with the glass surfaces being shared by the exterior and interior geometries. The interior geometry also included structural bodies for the seats, dashboard, gearbox and steering wheel to better represent sound wave absorption and reflection. Initially, the engineers considered windshield and front side windows composed of two layers of soda lime glass (SLG) laminated together with polyvinyl butyral resin, and monolithic SLG material for all other vehicle glazing. At a typical frequency of interest (1 kHz), the harmonic response simulation predicted that the SPL would be higher at the front end of the vehicle, with most of the noise coming from the windshield and front side windows. The combined simulation time for the ANSYS Mechanical analysis was 300 CPU hours over the range of 21 sampling frequencies.

**ANSYS Aero Vibro-Acoustics**
ansys.com/aero-vibro-acoustics

As validation for their results, the team collected SPL measurements from a wind tunnel using a microphone placed at the location of the driver's ear in a test vehicle. However, since the wind tunnel measurements were of the total interior SPL, the team also needed information about the flanking noise in addition to the glazing noise. They could ignore the tire and mechanical system contributions to the SPL in this study since the test vehicle was stationary and not in operation. To account for the flanking noise, the team performed a separate wind tunnel test with all glass surfaces shielded and then derived the total interior SPL. Overall there was excellent agreement between the simulation results and the experimental SPL data in terms of both trending and magnitude.

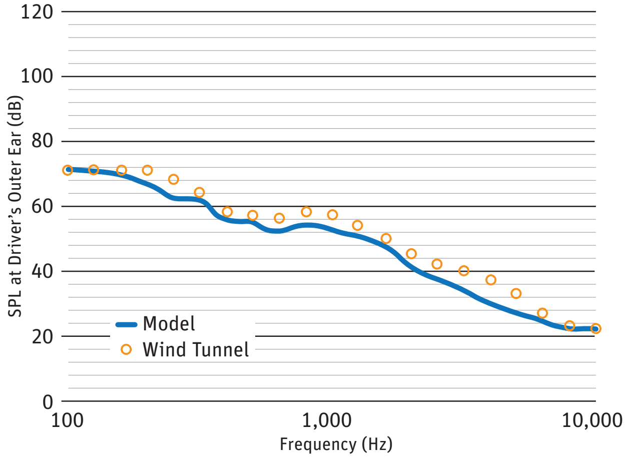
As an additional test, Corning analyzed what would happen if windshield and front side windows used a lighter-weight hybrid laminate, with the inner SLG layer replaced by a thinner layer of Gorilla® glass material. Though the simulations showed an acoustic penalty in terms of the glazing noise, the team judged the overall effect to be minimal since flanking noise is the dominant source at highway speeds. For both SLG–SLG and SLG–Gorilla glass laminate materials, using the smooth transition from the windshield to A-pillar compared to the standard under-flush transition reduced the perceived cabin SPL for lower frequency (under 500 Hz) exterior noise.



**Cabin SPL at 1 kHz shown in overall 3D (top) and cross-section (bottom) views, with red and orange representing the highest values**

> "The team estimated that it will reasonably be able to see a 30 to 50 percent improvement in the efficiency of its design and evaluation process, leading to a similar level of process cost savings."

At the end of the process, the Corning group had developed a model that provided powerful analysis for investigating full vehicle noise generation, transmission and propagation. With these initial results, the team estimated that it will reasonably be able to see a 30 to 50 percent improvement in the efficiency of its design and evaluation process, leading to a similar level of process cost savings. Although different vehicle designs may show different levels of importance for the noise transmission paths, this general DAVA evaluation approach enables the designer to focus on the most critical glazing and optimize the design.




**Comparison of DAVA method predictions with wind tunnel data at different noise frequencies, showing excellent agreement in both trending and magnitude for cabin SPL**


**References:**

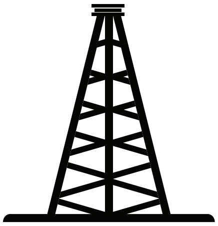
[1] J.D. Power. jdpower.com/cars/articles/jd-power-studies/vehicle-dependability-study-top-10-problems-3-year-old-vehicles (01/11/2018)

[2] Yu, C., *Automotive Wind Noise Prediction using Deterministic Aero-Vibro-Acoustics Method*, 23rd AIAA/CEAS Aeroacoustics Conference, AIAA AVIATION Forum, (AIAA 2017-3206).

# SURE FOOTING FOR ONSHORE DRILLING SITES

When the lifespan of working platforms made of boxes that raise oil workers' equipment over waterlogged areas did not meet expectations, engineers turned to ANSYS simulation. The time to develop new boxes has been reduced by 90 percent, and the lifespan is seven times greater than that of the previous design.

By **Dewei Wang**, Engineer, China National Petroleum Corporation,
Daqing Petroleum Equipment Group, Pumping Unit R&D, Daqing, China



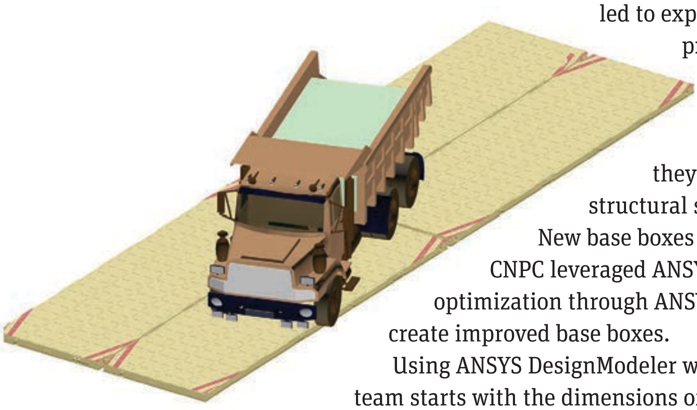
Site preparation is a concern in many onshore drilling and production projects. For sites in marshlands and regions near riverbanks there is the added complexity of working in areas with standing water (up to a couple of centimeters) surrounding the drill site. Water makes for unpleasant working conditions, shortens equipment life and can have negative impact on the surrounding environment. One solution is to build a foundation without a large environmental impact.

To avoid this water issue, China National Petroleum Corporation (CNPC), the third largest oil company in the world, tried to shift the operating season from summer to winter, but this led to an unsustainable rise in heating costs. Another fix was to truck in tons of dirt, which added significantly to the project costs, especially after environmental legislation was introduced in 2015 that requires all dirt that is transported into a site to be removed upon drilling completion.

**"Water makes for unpleasant working conditions, shortens equipment life and can have negative impact on the surrounding environment."**

The current solution is to use base boxes composed of rigid steel mesh and filled with dirt. When joined together, the boxes create a platform that allows workers and machinery to traverse the worksite while remaining above the water. Base boxes substantially reduce the amount of transported dirt that is required and therefore are superior to previous alternatives.

A typical field site has platform made from approximately 200 base boxes strung together into a single set that covers all of the necessary working locations on a field. These boxes carry workers and trucks weighing 60 tons. When originally designed, these base boxes required several senior engineers to perform manual calculations, which led to experiments with numerous prototypes. The process overall required dozens of experienced workers and nearly four months to develop the boxes. The expected design life for the original base boxes was five years, but they only lasted about two years because the structural strength was degrading faster than expected. New base boxes that had a longer lifespan were required. CNPC leveraged ANSYS Mechanical structural simulation and optimization through ANSYS Workbench to design, test, iterate and create improved base boxes.



**Simulated dump truck on base boxes**

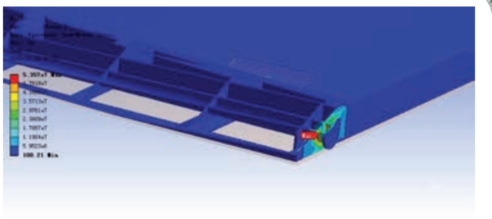
Using ANSYS DesignModeler within ANSYS Workbench, the CNPC design team starts with the dimensions of the base box for an initial design that they then modify using shape optimization to meet the constraints of the available manufacturing processes. They perform a linear buckling analysis using the static and modal analysis module with ANSYS Mechanical and determine the load limit for each box structure. The engineers optimize the design to obtain the best balance of strength, material and manufacturing costs. The thickness of the steel plate on the surface of the base box is the largest factor affecting the strength and cost of the box. For each additional millimeter of thickness in the steel plate, the cost increases by 2.5 percent and the weight increases by 125 kg per square meter. The parametric capability within ANSYS software is used to optimize the final thickness of the steel top sheet.

**Muddy conditions at a well site**

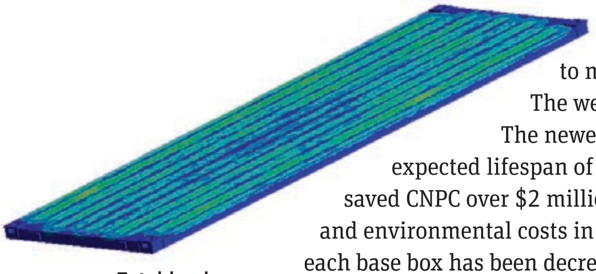
Using ANSYS software, CNPC engineers have replaced a time-consuming and expensive manual process with only 20 simulations that automate the design and structural parameters. Structural designs are now completed in two weeks, the development cycle is reduced by nearly 90 percent, and boxes are brought

> “Using ANSYS software, CNPC engineers have replaced a time-consuming and expensive manual process with only 20 simulations that automate the design and structural parameters.”

Four base boxes under a piece of machinery



Simulation of hanging strength load determines if the structure can hold the intended weight.



Total load simulation

to market three months earlier than in the past.

The weight of a single base box is reduced by 40 percent. The newest boxes have an expected lifespan of 15 years and have saved CNPC over $2 million in earth procurement and environmental costs in one year. The weight of each base box has been decreased by 400 kg, which reduces the amount of steel by over 70 tons at each well site. This means that related transportation costs are also cut by 6.8 percent.

Integrated ANSYS solutions have helped CNPC save millions of dollars by enabling it to more fully analyze and optimize base boxes for the applicable well sites. Design cycles now take one-tenth the time of the old manual process, and the environmental impact has been substantially reduced by removing the need to truck thousands of pounds of dirt in (and then out) for each well site.

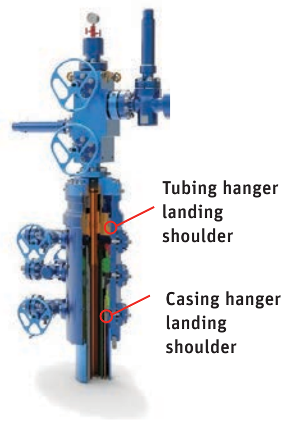
Base boxes

**Smart Strategies for Structural Simulations**
ansys.com/structural-simulations

# Designing Modular Wellheads

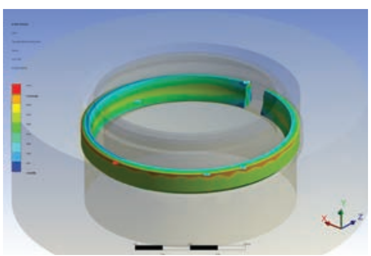
By **Wen Chun Lee**,
Product Design Engineer,
Singapore WEFIC Ocean
Technologies Pte. Ltd,
Singapore

Using the Modular Wellhead System from Singapore WEFIC Ocean Technologies reduces installation time for downhole equipment in the oil and gas industry. Employing a multistage system that accommodates different casing programs and working pressure, the system is easy to operate, safe and efficient. WEFIC engineers used ANSYS Mechanical to evaluate design alternatives for a key system component followed by physical testing to validate the finite element analysis results. This approach greatly reduced the number of test prototypes required, reducing development time by about 60 percent while ensuring reliability.

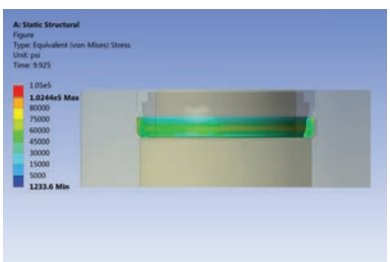



The wellhead sits at the surface of an oil or gas well and is the suspension point and pressure seal for the drill string, casing line and production tubing that are lowered into the hole at different stages of the well's lifecycle. Two types of equipment are attached to the top of the wellhead to control surface pressure: a blowout preventer during drilling and a Christmas tree (valves, fittings and spools used to control the flow out of the well) once drilling is completed. The wellhead's internal bore contains shoulders upon which the casing and tubing hangers are used to suspend casing strings and production tubing. While these shoulders prevent downward movement of the casing and tubing hanger, a mechanism is also required to resist pressure from downhole that would otherwise force the casing and tubing hanger upward, possibly damaging the wellhead and causing seal leakage, which reduces holding pressure. The most common approach to addressing this issue involves fixing the hanger with tie-down screws. This approach requires considerable installation time because of the need to install and torque up the large quantity of tie-down screws.

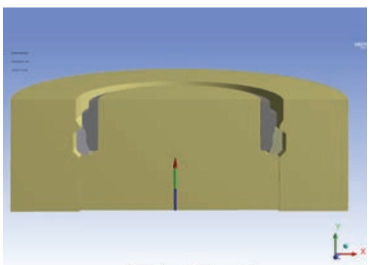
> *"Using ANSYS technology made it possible to finalize the design in about 40 percent of the time required in the past."*



**Stress experienced by lock ring under maximum loading**




**Another view of lock ring stress results**



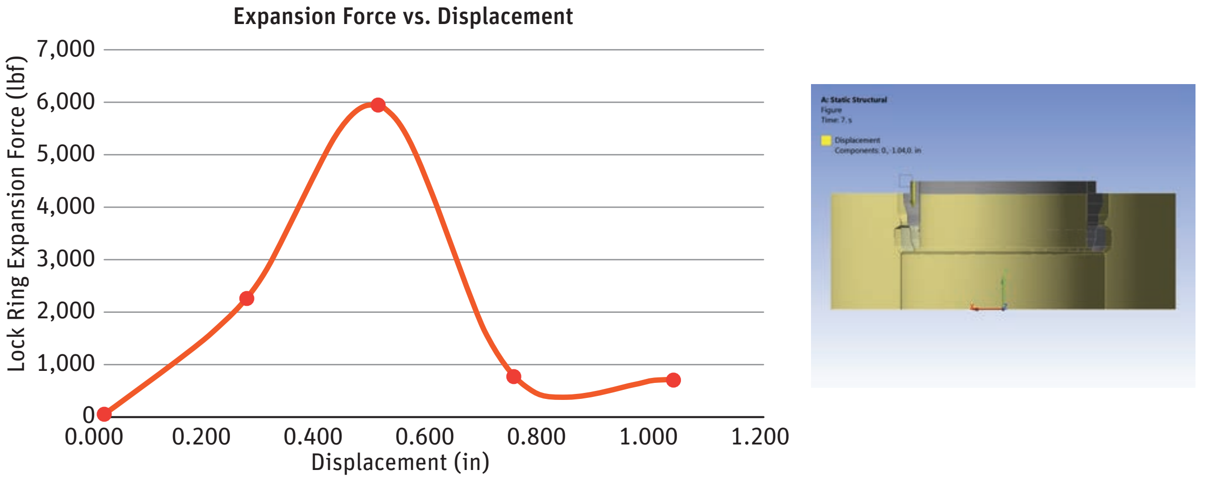
**Reaction force to match the pressure rating of the wellhead was generated by applying displacement boundary to move the ring upward.**

Singapore WEFIC Ocean Technologies Pte. Ltd. (WEFIC) provides high-tech petroleum equipment and technical services for the oil field engineering industry. The company's Modular Wellhead (MW-I), which can be used for both onshore and offshore application, reduces installation time with a lock ring that can be expanded radially until it sits in a groove in the wellhead. Installation is performed using a tool operated through the wellhead, riser and blowout preventer. This provides a significant reduction in installation time, which reduces drilling expense. Using the company's previous build-and-test methods, designing the lock ring for a new model wellhead would have required building and testing two to three prototypes, with about two months required for each. Engineers estimate that it would have taken about six months to design the lock ring this way. To design the lock ring for the new wellhead, the company used ANSYS Mechanical to get the design very close to the final product in only 10 weeks with only final adjustments required in the prototype phase. This made it possible to bring the product to market much faster.



**Lock Ring Design Specifications**

The lock ring must support upward forces resulting from pressure of 3,000 to 15,000 pounds per square inch (psi), depending upon the model of wellhead. The rings used on 3,000 and 5,000 psi wellheads interface with a single shoulder on the wellhead, while lock rings on the




**Maximum ring expansion force was retrieved by applying displacement boundary condition to expand the ring.**

10,000 and 15,000 psi models act against multiple shoulders. Lock rings used in all these models must withstand upward forces equal to the pressure rating of the wellhead while respecting material yield limits within a specified margin of safety. The lock ring is split radially, and a rotating tool is used to expand the lock ring into a groove in the wall of the wellhead bore. The tool is operated by hand, so the amount of force required to expand the ring is limited to approximately 200 foot pounds or less.

In the past, WEFIC engineers built and tested a physical prototype of each design iteration, which took about two months per iteration. The reduction in oil prices in the past few years spurred the company to look for ways to increase the efficiency of its design processes. WEFIC worked with CAD-IT Consultants to create virtual prototypes with ANSYS simulation software that reduce the number of physical prototypes that need to be built and tested. The company leveraged ANSYS Mechanical finite element analysis software to guide the design of a lock ring for a 5,000-psi and 10,000-psi wellhead.

Engineers defined the material of the ring as alloy steel with more than 100,000 psi yield strength. They needed to calculate both the force required to expand the ring and the stress throughout the ring when a force equal to the pressure rating of the wellhead is applied below the ring. They accomplished these goals by displacing the ring so that it expands radially at the start of the simulation. When the ring is fully expanded, radial displacement ends and the maximum force required to expand the ring is recorded. Next, another displacement boundary condition is used to move the ring upward. When the reaction force reaches the pressure rating of the wellhead, the simulation is stopped and the stress and deflection of the ring are evaluated.

### Faster Market Deployment

The first design iteration provided acceptable expansion force, but the stress values were above the design objectives. Engineers created additional design iterations by varying the values for the thickness of the ring and the angle of the cross section of the outer diameter of the ring where it contacts the wellhead. Over a series of 10 iterations, they reduced the stress values to below the design specification, while reducing the expansion force and the weight of the locking ring.

Engineers then built and tested a prototype. The test results met all the design specifications and closely matched the simulation results. Using simulation, it took only two weeks to design the lock ring and another two months to build and test the prototype. Using ANSYS technology made it possible to finalize the design in 10 weeks, which is about 40 percent of the time required in the past. Depending on the drilling conditions, well design and casing program, the WEFIC modular wellhead can save a substantial amount of drilling cost per well by reducing installation time.

This is only one example of how ANSYS tools have enabled WEFIC engineers to achieve a leaner product development process and deliver optimized and cost-effective solutions to the company's customers. Λ

*WEFIC is supported by ANSYS Channel Partner CAD-IT Consultants.*

# Turn Up the Heat in a Rooftop Heating Unit

In designing a new rooftop heating unit, AAON engineers needed to deliver higher airflow while maintaining the same footprint as an earlier design. The team used ANSYS computational fluid dynamics (CFD) software to calculate airflow through the heat exchanger of the unit and iterate to a design that meets energy efficiency, airflow and heat transfer requirements. The use of simulation in this project saved 60 to 80 hours of physical lab work compared to traditional design methods.

By **Chait Johar**,
Project Engineer,
AAON Inc.,
Tulsa, USA

AAON rooftop packaged units incorporate a tubular heat exchanger and air handling system for efficient heating of commercial and industrial buildings. To design the tubular heat exchangers used in rooftop heating units, engineers must maximize the transfer of heat from the hot gas flowing through the tubes to the air flowing through the cabinet. This delivers a high level of energy efficiency. The unit must also withstand the service conditions of the environment while minimizing cost and size.

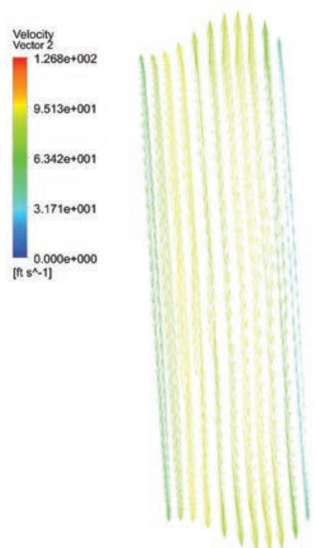
In the past, the design process involved building prototypes and performing physical measurements, such as testing the amount of heat that is transferred to the air flowing through the unit. Over the past few years, AAON has transitioned to using upfront simulation to optimize airflow and heat transfer prior to building physical prototypes. Simulation takes less time than building and testing a prototype, and it provides more complete diagnostic information, enabling engineers to iterate to an optimized design at a faster pace. AAON engineers achieved physical space, air handling and thermal efficiency goals while saving 60 to 80 hours of manual lab work.


**AAON RQ series rooftop units are engineered for performance, flexibility and serviceability.**

### Heat Exchanger Design Challenge

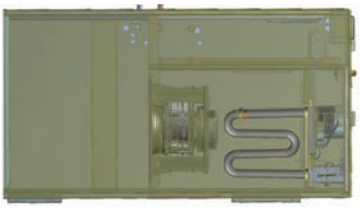
In designing the new rooftop unit, engineers had to increase the air handling capacity while maintaining demanding levels of efficiency and the same footprint as the previous-generation product. The hot gas enters the heat exchanger, is divided into internal tubes and is then released out of the unit. Fresh air is brought in for the next combustion cycle to supply oxygen. The shell of the heat exchanger guides air driven by a fan over the tubes. Traditional design methods rely upon handbook formulas and engineering judgment that typically focus on the surface area through which heat is transferred by convection between the hot gas and cooler air flowing through the cabinet. The heat transfer capability and efficiency of the unit are largely dependent upon the flow of air through the heat exchanger tubes: The airflow should be uniformly distributed around the tubes carrying hot gas.

A key limitation of build-and-test methods is that they generally do not account for the flow geometry and thus must make assumptions for the distribution of flow through the device. Due to these inherent inaccuracies in the traditional design process, soon after an initial concept design is generated, the lab builds a prototype and puts it through its paces. This process takes about eight working days. At this stage, the results are rarely good enough to meet product requirements, so the engineering team embarks on an iterative process of rebuilding and retesting the prototype. Engineers place thermocouples on the exterior of the tubes, which provide an accurate measure of the thermal performance of the prototype. But it is not practical to accurately measure the airflow around the tubes, so these tests provide very little diagnostic information on how flow patterns are impacting thermal performance.




**The axial, radial and tangential vector components of the centrifugal fans were determined by physical testing.**

**ANSYS CFD Heat Transfer**
ansys.com/heat-transfer



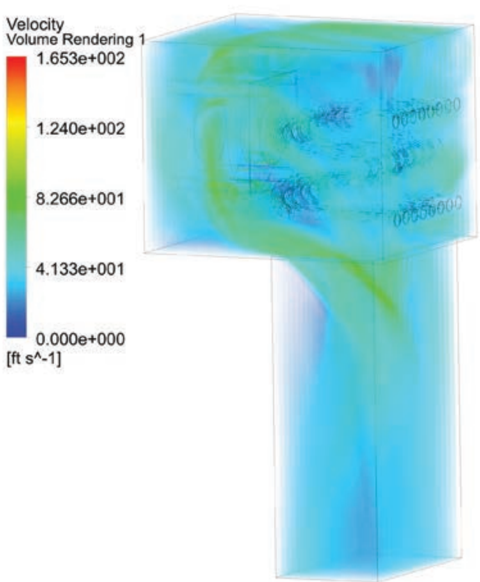
Unit skeleton with only the heat exchanger tubes (8 tubes) and the fan

### Simulation Now Drives Design Process

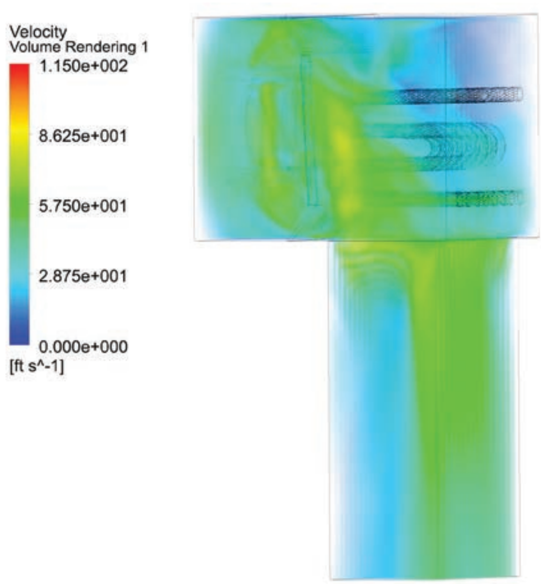
Over the past few years, AAON has transitioned to a new approach in which engineers use simulation to evaluate more design iterations in less time. Simulation provides more diagnostic information and iterates quickly to an optimized design. In designing the new RQA-B rooftop unit, engineers needed to move more heat and more air through a unit that occupies the same footprint but is taller than existing units. The new unit had to achieve an energy efficiency of 81 percent to be certified in all the regions in which it is being marketed.

Engineers created an initial design iteration and modeled the unit in ANSYS CFX computational fluid dynamics software. A master's student at Montana State University–Bozeman used physical testing to determine the axial, radial and tangential vector components of the airflow generated by different centrifugal fan sizes and speeds as a function of distance along the fan's axis of rotation. These values were used as boundary conditions in the CFD model. The wall function approach was applied to model the boundary layer profile with a reduced cell count. Inflation layers were employed in the fluid domain near the tubes to provide a sufficiently fine mesh to accurately capture this region, where the flow experiences rapid changes in velocity, pressure and temperature. The placement of the first node in the mesh at the end of the tubes is particularly important. A non-dimensional distance based on local cell fluid velocity called y+ ensures

> **"Simulation takes less time than building and *testing a prototype* and provides more complete diagnostic information, enabling engineers to iterate to an *optimized design* at a faster pace."**




Initial run showing air leaving the fan and exiting the cabinet. Much of the air did not pass through the heat exchanger tubes.



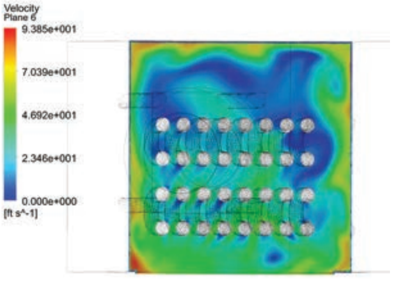

Baffles were added to divert the airflow and improve flow distribution.

that simulation accuracy in this area is acceptable. With the k-epsilon turbulence model that was used in this case, a y+ value of less than 100 is recommended. AAON engineers tweaked the mesh to keep y+ below 100.

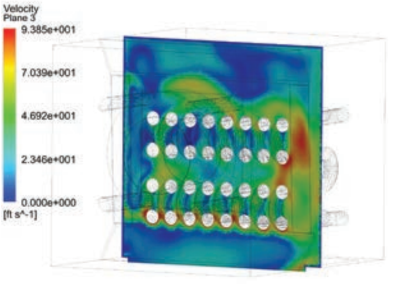
**AAON Reduces Physical Prototyping**

The simulation results showed that the energy efficiency of the initial design was well below the required levels. AAON engineers also built a prototype of the initial design and used it to validate the simulation results. Looking at the flow and temperature distribution in the cabinet and tubes, AAON engineers could see that a significant proportion of the air flowed past the heat exchanger tubes into the outlet without ever coming into contact with them. Based on these results, AAON engineers added baffles to the cabinet to redirect flow that had been bypassing the tubes. Using simulation, they were able to digitally explore different baffle positions and geometries, along with different positions of the tubes relative to the sheet.

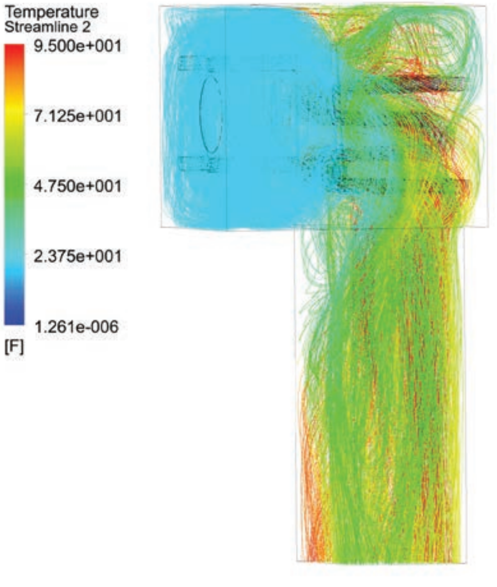
Each simulation run took 6 to 8 hours on a single core, so AAON engineers set up multiple runs when they left work in the evening. They are now using a computer with 4 cores, which has reduced the solution time to 1.5 to 2 hours. Guided by the flow simulation results, engineers rapidly iterated to a design that more efficiently routes air through the cabinet. The average air velocity through the heat exchanger tube faces increased by almost 25 percent, and the temperature into the outlet went up several degrees with the same flow rate through the cabinet. Engineers built a prototype of the optimized design, and the results closely matched the simulation results, providing an efficiency of 82 percent. AAON is currently ramping up production of the new rooftop unit and preparing to bring it to market. The AAON test lab manager estimated that, in this one application, simulation saved 60 to 80 hours of physical lab work, representing a substantial cost savings. Simulation also generated incremental revenues by bringing the product to market earlier than would have been possible using the build-and-test method.



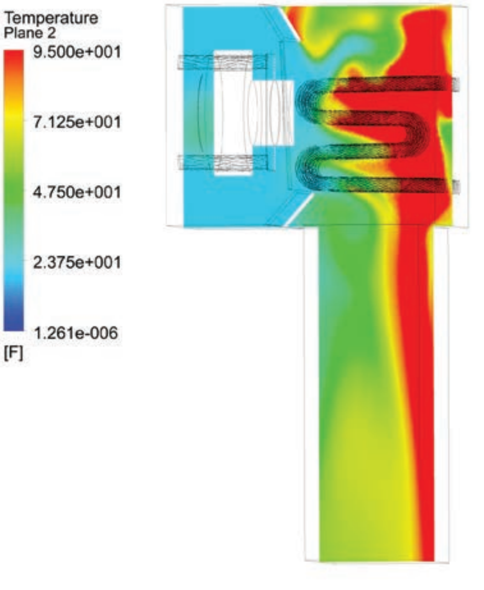

**Flow velocity plot for initial design shows much of the air is flowing through the cabinet perimeter.**




**Flow velocity plot for final design with baffles added shows much more air is flowing through the tubes.**




**Streamlines depict the temperature changes through the cabinet.**




**Temperature on a cross section of the unit shows air temperature rising downstream of the cabinet.**

# **Simulation** in the **News**

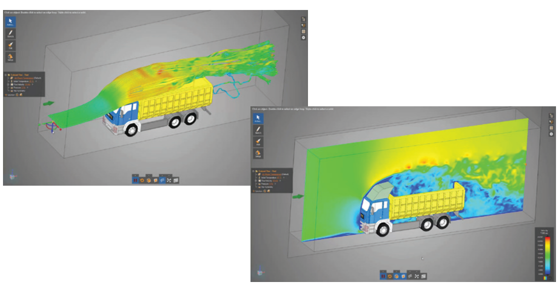
## ANSYS 19 TAMES PRODUCT COMPLEXITY AND SPURS PRODUCTIVITY

ANSYS 19 empowers engineers to develop groundbreaking products, from autonomous vehicles to smarter devices to more electric aircraft, at an unprecedented pace. With enhancements across the entire industry-leading portfolio — from structures to fluids and from systems and semiconductors to electromagnetics — longtime users will notice dramatic improvements in time to solution, while new users can take advantage of state-of-the-art functionality. ANSYS 19 helps engineers manage complexity and enhance productivity, so that engineering and design teams achieve more accurate answers across the broadest range of applications — making simulation even more pervasive.


## REAL-TIME DIGITAL EXPLORATION

newelectronics, February 2018

The commercial release of ANSYS Discovery Live empowers millions of engineers around the world to confidently simulate designs in real time quickly and more economically. Discovery Live is expanding Pervasive Engineering Simulation — enabling engineers to pose what-if questions upfront in the design process to rapidly explore thousands of design options and to receive immediate feedback.



## ANSYS ACQUIRES ADDITIVE MANUFACTURING SIMULATION LEADER 3DSIM

3DPrint.com, November 2017

ANSYS has acquired 3DSIM, a developer of powerful simulation software for metal additive manufacturing. This has created a combined simulation solution that is now the industry's only complete additive manufacturing simulation workflow. Additive manufacturing is the most rapidly growing and disruptive segment in the engineering market.

## TEENS SEARCH FOR WAY TO IMPROVE MAGNETIC RESONANCE IMAGES

CBC, October 2017

High-school students are using ANSYS simulation to develop MRI technology for noninvasive blood testing. By using MRI technology, the students can determine the composition of blood without having to penetrate the skin.

## ADDITIVE MANUFACTURING PRESENTS AN OPPORTUNITY TO DISRUPT THE SUPPLY CHAIN

Auto Tech Review, October 2017

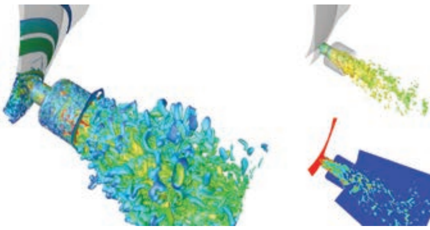
ANSYS CEO Ajei Gopal provides insight into Pervasive Engineering Simulation, additive manufacturing and automotive megatrends in this interview.

*"Simulation now pervades the entire product lifecycle. It is not just for the validation phase."*

—**Dr. Ajei Gopal**, CEO, ANSYS

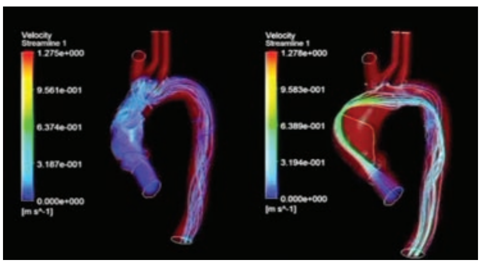
## 2018 ANSYS HALL OF FAME DEMONSTRATES PERVASIVE ENGINEERING SIMULATION

Every year, the ANSYS Hall of Fame Competition reveals the wide range of exciting uses for our software solutions from organizations around the world. From huge multinational corporations to small, creative startups, the commercial world employs engineering simulation to deliver reliable products to market quickly. And students, instructors and academic researchers leverage simulation to expand engineering knowledge.



Delphi

FTGM




Safran

## CAE TURNS TO HIGH-PERFORMANCE COMPUTING

### HPC Yearbook 2017-18, January 2018

In this interview, Wim Slagter of ANSYS explains the value of HPC technology for computer-aided engineering. As the barriers to HPC are reduced, more companies are able to leverage this technology.

*“HPC is helping manufacturers cut costs and create new revenue streams because they can design completely new products they had not previously considered.”*

— **Wim Slagter,**
Director of HPC and Cloud Alliances, ANSYS

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## ANSYS STARTUP PROGRAM GIVES AFFORDABLE CAE, HPC AND CLOUD TO THE MASSES

### Engineering.com, October 2017

Rescale and ANSYS are spearheading a simulation and cloud computing program that enables startups to quickly and cost-effectively bring their innovative products to market.

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## BENCHMARK AN ANSYS MODEL FOR FREE

### Digital Engineering, October 2017

To determine how your structural mechanics or fluid dynamics model performs on an HPC system (rather than your workstation), ANSYS has teamed with HPC partners. Through this program, you can benchmark your own model to determine the hardware solution that delivers the best return on your software and hardware investment.

## ANSYS SUPPORTS FERRARI ENDURANCE RACING WINS

### Today’s Motor Vehicles, December 2017

Securing its fifth WEC constructor’s title and twenty-fourth overall, Ferrari uses ANSYS computational fluid dynamics (CFD) solutions to maintain best-in-class endurance-oriented aerodynamic performance.

*“ANSYS enables our team to quickly test multiple configurations between each lap and provides accurate insight — empowering our team to improve our speed and reliability in real time.”*

— **Ferdinando Cannizzo,**
GT Technical Coordinator, Ferrari Competizioni

ANSYS, Inc.
Southpointe
2600 ANSYS Drive
Canonsburg, PA U.S.A. 15317

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**AdvantageAddressChange@ansys.com**