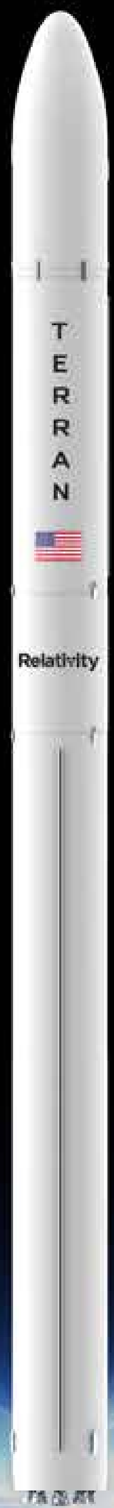
ANSYS

Excellence in Engineering Simulation

ADVANTAGE

ISSUE 3 | 2018



"When we said we wanted to 3D-print rockets, a lot of people thought we were crazy."

Spotlight on Additive Manufacturing

Additive Manufacturing Success through Simulation

By **Shane Emswiler**
Vice President and General Manager – Electronics, Fluid and Mechanical
ANSYS

Additive manufacturing, also known as 3D printing, is capturing the imagination of the international business world — and with good reason. The ability to manufacture highly customized parts has the potential to significantly reduce production costs and materials waste, while improving customer satisfaction and profit margins. Additive manufacturing also supports product innovation and market responsiveness, because designs can go from a digital file to a finished product in mere minutes.

In today's world of hyper-competition, many leading businesses focus on winning sales by catering to customers' individual needs. Additive manufacturing supports mass customization by allowing fundamental designs to be easily adjusted to include highly specific features or different materials compositions. This not only helps consumer products companies develop customized offerings cost-effectively but, for example in the healthcare industry, it means that medical devices can be easily fitted to individual patients' bodies to improve outcomes.

While metal additive manufacturing holds incredible promise to deliver strategic and financial benefits, today it is primarily used by large corporations, like aerospace firms, with sophisticated product designs. With their need to design products with highly complex geometries, composed of high-endurance materials mixtures these companies are logical first adopters of additive manufacturing.

However, as the cost of entry is lowered — primarily due to less expensive metal additive manufacturing equipment — more companies will explore the promise of 3D printing. To do so, they must manage a number of practical challenges. These challenges include adopting new workflows, accommodating unfamiliar production parameters, and eliminating production errors and waste. This last challenge is not an insignificant one: The cost of additive manufacturing powders is currently much higher than traditional materials. A failed printing job can be surprisingly expensive.

But there is good news. Just as simulation has been optimizing traditional engineering and production processes for more than 40 years, simulation is evolving to meet these new challenges. Engineers can now use simulation to determine not only how their product design will perform under real-world conditions, but also exactly how that design will print on a specific machine. Everyone involved in the production process, from the designer to the machine operator, can collaborate on a common technology platform and share complete visibility into the additive manufacturing outcome.

“Engineers can now use simulation to determine not only how their product design will perform under real-world conditions, but also exactly how that design will print on a specific machine.”

To make this vision a reality, ANSYS has developed extensions to its flagship simulation solutions for additive product design while also introducing new tools specifically aimed at optimizing engineering and production processes associated with additive manufacturing. ANSYS customers can enter the world of additive manufacturing with a low level of risk, because they are leveraging a familiar industry-leading technology — and using the proven power of simulation to protect their profit margins.

This issue of *ANSYS Advantage* highlights some of the new simulation capabilities that support metal additive manufacturing, along with success stories from customers who are already capitalizing on this new production method. We hope this magazine will help you think about how simulation-enabled additive manufacturing can become a competitive advantage for your own business.

Table of Contents

Spotlight on Additive Manufacturing

ABOUT THE COVER

Relativity Space has a unique vision: to leverage additive manufacturing technology to 3D-print rockets that can be launched into space.
Learn more on page 10.

SIMULATION@WORK

DEPARTMENTS

WEB EXCLUSIVE

Join the simulation conversation
ansys.com/Social

Welcome to *ANSYS Advantage*! We hope you enjoy this issue containing articles by ANSYS customers, staff and partners.

The Editorial Staff, *ANSYS Advantage*
ansys-advantage@ansys.com

Executive & Managing Editor
Chris Reeves

Editorial Advisers
Amy Pietzak, Tom Smithyman

Editorial Contributor
ANSYS Customer Excellence North America

Senior Editor
Tim Palucka

Designer
Dan Hart Design

Editors
Erik Ferguson, Kara Gremillion, Thomas Matich, Mark Ravenstahl, Walter Scott, Terri Sota

Art Director
Ron Santillo

Cover Illustration
Gregg Weber

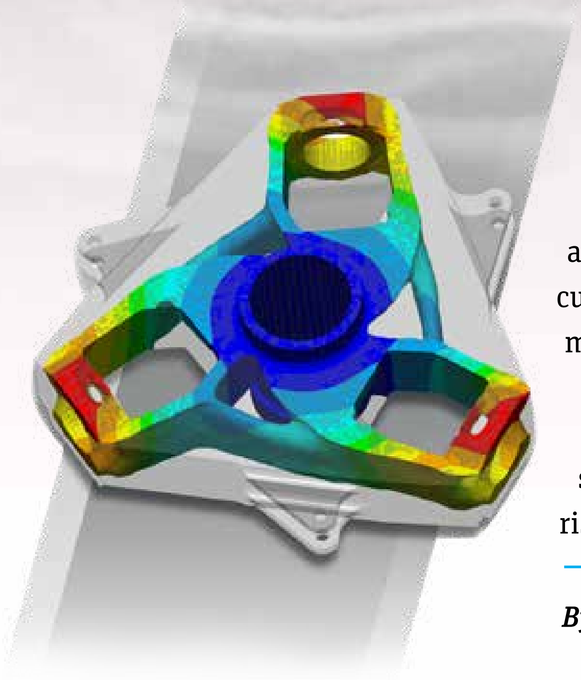
ANSYS, Inc.
Southpointe
2600 ANSYS Drive
Canonsburg, PA
15317
USA

Subscribe at ansys.com/magazine

Realize Your Product Promise®
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.

Additive Manufacturing:
A New Frontier for Simulation



ADDITIVE MANUFACTURING — popularly known as 3D printing — is poised to revolutionize both engineering and production. With its capability to quickly turn a digital design into a physical product, additive manufacturing supports mass customization and fast response times. But high materials costs require product developers to get their designs right the first time and every time. Recently, *ANSYS Advantage* discussed how simulation can maximize results and minimize risks with two ANSYS experts.

By ANSYS Staff

> “***Additive manufacturing*** **should make strategic sense as part of a larger product development and manufacturing strategy.**”

ANSYS Advantage: ***What exactly is additive manufacturing? And why is the business world so excited about it?***

Brent Stucker: Additive manufacturing is a technology that produces three-dimensional parts by building them up, layer by layer. It gets its name from the layers of materials that are being added — as opposed to taken away, as in some other production processes. It is popularly known as 3D printing because it involves sending a digital design to a machine that produces it very quickly.

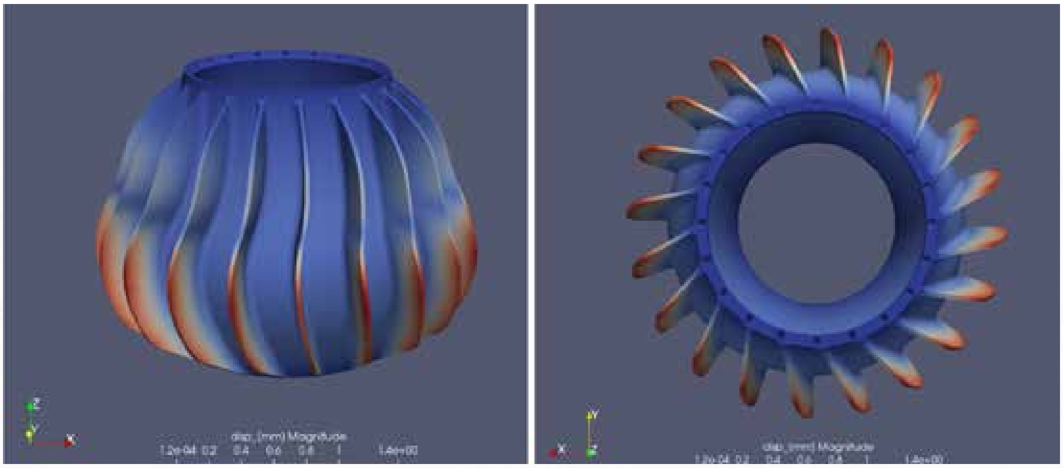
Additive manufacturing began as a way to produce prototypes rapidly, but it is gaining broader acceptance as a final production strategy because it has many advantages over traditional processes. Obviously it allows companies to quickly progress from a digital file to a finished product. But it also enables the production of very complex shapes, as well as “one off” designs that meet the needs of a specific customer. There is also the potential to develop highly customized mixtures of materials that deliver targeted performance characteristics.

Dave Conover: Recognizing the potential of this new technology, ANSYS has developed tools for simulating metal additive manufacturing processes. We are focusing our development on metal right now, but we do plan to add more materials in the future. The reason why metal is our focus is that it is the area where our customers are investing and seeing the greatest opportunity. It is also the area where trial and error costs them the most money, and thus a metal simulation tool can have the greatest financial impact in the near term.

AA: ***How broadly is metal additive manufacturing being applied today? And what’s the future potential?***

BS: Today, the early adopters of metal additive manufacturing are businesses with highly complex parts that are subject to extreme conditions — for example, aerospace companies. There is a high cost of entry for additive manufacturing, because adding new production equipment is an expensive proposition. New expertise needs to be added to the manufacturing staff. There is also a high risk associated with production failures, because metal powders and other 3D printing materials are costly.

ANSYS Topology Optimization
ansys.com/to



ANSYS is partnering with Renishaw, a leading engineering and scientific technology company, to understand how simulation can effectively predict stresses and failure modes during the additive manufacturing (AM) process. ANSYS Additive Print predicted that these very fine turbine blade tips — each measuring just 1.3 mm across — would deform during the high thermal stresses associated with the AM process. (The red areas designate regions of high stress.) Identifying these potential failure modes enables designers and machine operators to adjust part geometries or machine parameters to minimize the risk of costly printing errors.

DC: So it makes sense that the leaders in metal additive manufacturing are in industries like aerospace, where the benefits are great enough to make these challenges worth overcoming. But eventually, as we work together to develop solutions to these shared challenges, additive manufacturing is going to become practical for virtually any manufacturer, in any industry.

AA: *What role can engineering simulation play in solving these challenges?*

DC: When you think about these challenges — high costs and high risk — then engineering simulation just makes sense for companies looking to explore additive manufacturing as a strategy. It makes sense because simulation has been proven, over the course of 40-plus years, to maximize certainty and minimize risk. By leveraging simulation, companies can predict whether a digital design will be produced successfully, before they metaphorically hit the "print" button.

"Additive manufacturing means new materials, including metal powders, as well as new design and production workflows, and new physical constraints."

BS: The beauty of simulation is that it can analyze the entire additive manufacturing process, from the earliest design to the finished product. Companies can not only rely on traditional simulation tools to ensure that performance criteria are met for the end product — but now they can also simulate the production process via new process simulation solutions. They can answer critical questions like, "Which machine should I send my design to?" and "Which material microstructure is the right one for this design?"

AA: *How can simulation help companies who are just beginning to explore additive manufacturing?*

BS: Just as product development teams have historically used simulation to optimize key product characteristics, specialized tools can now help them optimize their designs for the new environment of additive manufacturing. Engineers can visualize distortion and stress on a layer-by-layer basis. They can study part tolerances and build failures, which are key risks for additive manufacturing. Parts produced via additive manufacturing will have very different characteristics than cast or forged parts — and simulation helps engineers understand and address those key differences.

DC: As Brent mentioned earlier, these companies will be investing in new production equipment. Today there are specialized simulation tools that are designed to interact with these machines. Engineers and 3D printer operators can work together to identify the optimum machine and material parameters — before they try and fail. They can learn and improve continuously by comparing the predicted machine behavior, and the predicted part characteristics, with what actually occurs during printing. They can reduce printing failures and the number of prototypes required.

While additive manufacturing simulation is new, this is actually the same value proposition simulation has always offered: Minimize risk, cut time and costs, and maximize product innovation.

> **“There’s really no limit to the benefits that can be realized as additive manufacturing gains broader acceptance.”**

AA: ***What are the specific simulation capabilities that can be applied to the additive manufacturing process?***

DC: Some of the simulation functionality that applies to additive manufacturing is already in broad usage for traditional product development challenges. For example, engineers have been simulating different materials compositions for decades. They have been optimizing their products’ topology and manipulating geometry to optimize both production processes and performance in the field. They have been conducting thermal and structural analyses. Engineers have also historically studied part shape, distortion and stress. What’s exciting today is that there are new, specialized tools that consider all these aspects in light of the unique conditions of additive manufacturing, or 3D printing. Additive manufacturing means new materials, including metal powders, as well as new design and production workflows, and new physical constraints. But ANSYS makes it easy to accommodate these changes by offering a new generation of solutions that are an extension of the capabilities in our traditional software suite.

BS: Equally exciting are brand new software tools that have been created specifically to optimize the production of engineers’ designs on today’s state-of-the-art additive manufacturing equipment. For the first time, ANSYS has developed simulation software specifically for machine operators. These production experts can accurately build the design in a virtual environment, increasing confidence that a specific product geometry will print optimally on a specific additive manufacturing machine. This software interacts with traditional design software and can operate independently or as a part of the ANSYS technology platform, ensuring a closed-loop design-and-build cycle that maximizes successes and minimizes failures. (Editor’s note: Learn more about specific ANSYS solutions for additive manufacturing on page 19.)

AA: ***Why has ANSYS made the decision to invest in new solutions that are specific to additive manufacturing?***

DC: Today, the traditional boundaries between functions are disappearing as it becomes possible

The ANSYS Vision for Simulation-Driven Product Development in Additive Manufacturing
ansys.com/am-vision

Courtesy Renishaw

For a single turbine blade, ANSYS Additive Print proved extremely accurate in predicting deformation during the AM process, when compared to an actual print run. By compensating for the stresses identified by ANSYS Additive Print, the final part was extremely close to the desired geometry. Without compensation, the part would have been considered a failure, resulting in wasted time, equipment capacity and materials costs. ANSYS has estimated that, for complex geometries such as turbines, a single failed print run could mean tens of thousands of dollars in wasted costs.

[redacted]

to design something and produce it quickly. To take advantage of these kinds of technology breakthroughs, the whole company needs to collaborate much more closely — and emerging simulation solutions facilitate that. ANSYS has new tools that can be used by different functions within the business, including production operators and materials engineers, but they are united by one technology platform.

ANSYS feels a real responsibility to monitor industry trends and help our customers capitalize on new opportunities like additive manufacturing that can add value — not just in the engineering function, but across the company. It is just one more aspect of our commitment to pervasive simulation.

BS: It is impossible to overstate the impact additive manufacturing can have on a traditional manufacturing company. This technology is a game-changer. Medical devices can be produced with patient-specific geometries. Huge spare parts inventories? Those will be a thing of the past, as replacement parts can be produced when they've been ordered. Products that operate in extreme environments, such as in the oil and gas industry, can be produced with new hybrid materials compositions that take their durability to a new level.

There's really no limit to the benefits that can be realized as additive manufacturing gains broader acceptance. It's going to increase collaboration across the company — driving out time and costs from the design-and-build cycle — while giving engineers new freedom to create and deliver highly innovative products. In the next five to 10 years, additive manufacturing is going to become a competitive imperative, and companies that don't adopt this practice will be left behind.

> **"ANSYS has developed tools for simulating metal additive manufacturing processes."**

AA: ***How can companies begin to adopt an additive manufacturing strategy?***

BS: One of the most common misconceptions is that additive manufacturing is an "all or nothing" proposition. I think companies are discouraged by the prospect of replacing all their production equipment with new additive manufacturing technology. But that's simply not the case.

Few products are manufactured, start to finish, via additive manufacturing. Instead, key components are 3D printed, then assembled with traditionally produced components to form products that represent the best of both worlds. So traditional manufacturers can begin by asking, “What parts of my products lend themselves to additive manufacturing?” These might be parts with complex geometries, those subjected to special stresses, or those with a high level of customization.

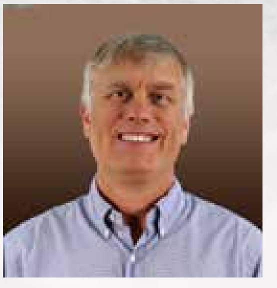
Additive manufacturing should make strategic sense as part of a larger product development and manufacturing strategy that also includes traditional manufacturing capabilities.

DC: Similarly, companies should begin to add simulation capabilities specifically developed for additive manufacturing that integrate seamlessly with their existing simulation portfolio. They should consult with experienced partners like ANSYS about how they can leverage simulation in a targeted way to begin to enter the realm of additive manufacturing, at a relatively low level of risk and investment.

“While additive manufacturing is a relatively new technology, best practices already exist.”

While additive manufacturing is a relatively new technology, best practices already exist. ANSYS has worked with the earliest adopters — and can help new adopters implement those practices in a way that makes the best sense for their own business model.

Brent Stucker
Director
Additive Manufacturing



Dave Conover
Chief Technologist
Additive Manufacturing

Breaking the Mold

Relativity Space was founded in 2015 with a unique vision: to leverage additive manufacturing technology to 3D-print rockets that can be launched into space. This ambitious California-based startup is poised to change the global aerospace industry by making rockets exponentially faster, cheaper and simpler to produce. Already on its way to rewriting the rules for commercial satellite launches, Relativity hopes to eventually manufacture its 3D-printed rockets on Mars — where this innovative, affordable technology could be used to support human colonization.

By ANSYS Staff

Relativity Space aims to be the first company to launch a rocket produced entirely via 3D printing, or additive manufacturing. The company's Aeon rocket engine includes just 100 parts and is produced in three print runs.

When they met as undergraduates at the University of Southern California, Tim Ellis and Jordan Noone bonded instantly over their shared love of rockets. They worked together in USC's Rocket Propulsion Lab, formed by a group of students who wanted to be the first undergrads to send a rocket into space.

After graduation, Noone went to work for SpaceX and Ellis was hired by Blue Origin. The two reconnected in 2015 and decided to launch a startup called Relativity Space. Their new company was based on a novel concept: producing rockets via emerging 3D printing technology, also known as additive manufacturing (AM). While other aerospace companies were printing vehicle components, Ellis and Noone wanted to be the first to produce an entire rocket via AM technology.

The founders recognized that there are many advantages to additive manufacturing. The structure can be simplified. A rocket made of 100 parts using AM is going to be much more structurally stable and inherently stronger than one composed of 10,000 separate components. AM significantly streamlines assembly, and makes the end-to-end supply chain much simpler and more seamless. AM also removes restrictions on novel geometry and opens up design options.

"When we said we wanted to 3D-print rockets, a lot of people thought we were crazy," says Noone, the company's chief technology officer. "But people with experience in the industry saw the potential in our idea." One of those people was billionaire investor Mark Cuban, who committed $500,000 in funding to get Relativity off the ground. Relativity was also accepted into the prestigious Y Combinator program, which offers funding and strategic consulting to entrepreneurial companies.

"There is no way other than simulation to get that level of fidelity and confidence when you're managing an additive manufacturing run."

Backed with capital and a business plan, there was only one major issue: Ellis and Noone could not find a 3D printer big enough to produce a rocket. So the pair did what any visionary would do. They built their own printer.

Measuring 15 feet tall and nine feet in diameter, Relativity's Stargate is the world's largest 3D printer. The startup is currently using ANSYS Additive Suite to optimize the printer's performance.

STARGATE: LAUNCHING A NEW GENERATION OF AM

Nine feet in diameter and 15 feet tall, the resulting machine — called Stargate — resides at the company's headquarters in Los Angeles, California, and is the world's largest 3D printer.

The complex process of engineering the Stargate printer was managed in part via simulation. Both Noone and Ellis had used ANSYS software at their previous jobs, and they contacted ANSYS within eight days of founding Relativity Space. "ANSYS software is very well regarded in the global aerospace industry," notes Noone. "It's a trusted technology, known to be extremely accurate as well as easy to use. We knew we needed ANSYS to bring our ideas to life."

Relativity was able to quickly access software licensing through the ANSYS Startup Program. "Partnering with ANSYS early on was critical in accelerating the design cycle for Stargate, as well as making sure we got the physics right," says Noone. "For example, we simulated the computational fluid dynamics inside the printer to optimize material flows during the actual printing process."

> **"We knew we needed ANSYS to bring our ideas to life."**

While designing and building the printer took time and money, the investment was significantly lower than the tens of millions of dollars required to buy fixed tooling and build a manufacturing plant.

Using a 3D printer also maximizes the engineering team's flexibility as it iterates on product designs. "It might take months, and millions of dollars, to retool a traditional manufacturing facility," Noone points out. "But we can achieve a new engine design in 18 days, and a completely new vehicle iteration in 30 days. That gives us unmatched agility and responsiveness in the aerospace industry."

AEON: THE FIRST 3D-PRINTED ROCKET ENGINE

Engineers at Relativity also relied on simulation via ANSYS to design Aeon, the first rocket engine produced solely with additive manufacturing technology. Capable of producing 15,500 pounds of thrust at liftoff, Aeon is composed of a nickel alloy. With only three parts, the engine is manufactured in three separate print runs.

The Relativity product development team leveraged ANSYS Fluent software to conduct computational fluid dynamics (CFD) simulations of the engine's injection element, cooling holes and manifold. By optimizing flows in these areas, engineers were able to reduce the overall design cycle and the high costs of physical testing.

The company's engineers also used ANSYS Mechanical to assess structural stresses inside the Aeon engine during important events such as liftoff. More than 100 test fires have confirmed that the ANSYS simulations effectively optimized Aeon's strength and structural stability.

OPTIMIZING RESULTS VIA ANSYS ADDITIVE SUITE

As a producer of some of the largest 3D-printed objects in the world, Relativity Space was naturally interested when ANSYS introduced ANSYS Additive Suite in 2018. In fact, Relativity was the first official customer for this new family of software that optimizes the 3D printing process, from materials composition to machine settings.

"We are thrilled with ANSYS Additive Suite," says Noone. "By simulating the results of each print run — before we actually commit materials and machine time — we are substantially lowering our risk exposure."

Noone notes that producing huge part shapes from metal materials means a very high cost of trial and error. The new capabilities in ANSYS Additive Suite enable the Relativity engineering team to predict and address areas of deformation, ensure geometric accuracy, eliminate material waste and avoid potential machine damage — among other benefits. Says Noone, "There is no other way to get that level of fidelity and confidence when you're managing an additive manufacturing run."

Relativity's Stargate is the world's largest 3D printer.

NEXT STOP? MARS

The initial application for Relativity's Aeon engine and its launch vehicle — called Terran — will be in the commercial satellite market. The company occupies a unique niche in this industry, offering pay-per-launch services for satellites in the 1250-kilogram range, or about the size of a small car.

With its capability to manufacture a new launch vehicle every 60 days via AM technology, compared to one year of development time using traditional manufacturing methods, Relativity hopes to dominate this fast-growing market segment. It is already signing up customers for its first launch, scheduled for 2020.

But Relativity Space's long-term vision reaches much farther. This energetic startup hopes to be the first company to produce and launch 3D-printed rockets on Mars.

"We envision human colonies thriving on both Earth and Mars," predicts Noone. "However, there will initially be very scarce resources on Mars. The flexible, relatively lightweight nature of AM technology will provide a fast, affordable means to build what humans will need to survive — and manufacture rockets to get back to Earth. Everything we have done in terms of engineering is focused on that end goal. For example, the Aeon engine is powered by oxygen and methane, two propellants that will be very easy to produce on Mars."

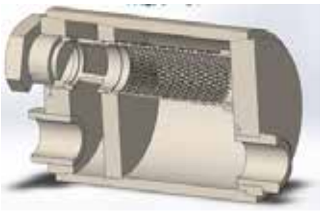
"We recognize that this vision sounds ambitious, but we hope to inspire other startups to join in the effort to make humanity multi-planetary. Just because your company is small doesn't mean you can't dream big," concludes Noone.

Introduction to ANSYS Additive Print
ansys.com/intro-additive-print

Including Simulation in the **Additive Manufacturing Workflow**

By **Louise Geekie**
Project Manager
Croft Filters, Ltd.
Warrington, UK

When designing a new industrial filter, Croft Filters needed to overcome warping during the selective laser melting additive manufacturing process. By leveraging one of ANSYS's additive manufacturing simulation solutions, Additive Print, in their design-to-print workflow, engineers were able to quickly generate a printable design and avoid multiple build failures, thus reducing time to market and prototyping expenses by 50 percent.



Filter body produced by additive manufacturing shown in housing

To develop a new filter that would decrease the pumping energy required by the industrial end user, Croft engineers reasoned that aligning the holes with the flow would reduce the amount of pumping energy required to drive the fluid through them. This filter design required intricate internal contours that cannot practically be produced by traditional manufacturing methods, so Croft turned to metal additive manufacturing. The selective laser melting (SLM) additive manufacturing process employed produces parts by sequentially melting tiny areas of a powder bed with a moving laser.

As each melted section cools, it experiences compressive and tensile forces, but is constrained by its attachment to nearby solid areas. The resulting residual stresses may cause the part to warp. In the past, Croft engineers used trial-and-error methods to eliminate warpage or at least reduce it to the point that dimensional tolerances could be met. By using the ANSYS Additive Print solution to guide their efforts in solving distortion problems, they have cut solution time in half and reduced prototyping expenses by about the same amount.

Filter Built by SLM Process

During the SLM process, a wiper pushes a thin layer of powdered metal (316L stainless steel, in this case) across a build plate, and a laser tracks across the layer to melt the areas of that layer that will form a cross section of the part. As each layer is completed, another layer of powder is applied to the partially built part, and the laser melts a new cross section. The cycle continues until the part is complete.

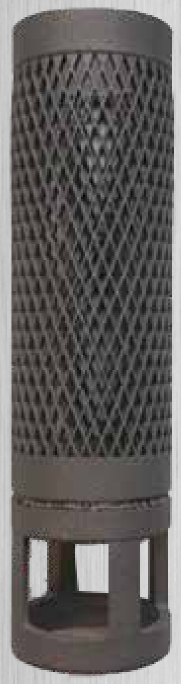
As each section of the part on the top layer cools, the solid underlying layers resist the thermal contractions, applying a tensile stress to the top layer. Likewise, the top layer applies compressive stresses to the solid area beneath it. The geometry of the part and auxiliary structures added to support overhangs and conduct heat have a major but difficult-to-predict effect on residual stresses. Areas that are relatively free to move have less residual stress, while areas restricted from moving have a higher level of residual stress. In this case, the finished part did not meet manufacturing tolerances because residual stresses generated several distortions in the x and y planes and elongation in the z plane.

In the past, Croft engineers would have relied on trial-and-error methods to determine what changes in the part orientation, support structures, machine parameters, material specifications and component design would enable them to meet manufacturing tolerances. It typically took four weeks to achieve a satisfactory part using this approach and consumed considerable resources, including engineering time, to generate new design iterations. It also took more build time on additive manufacturing systems and more powdered metal materials to produce additional prototypes.

Simulation is Used to Solve Additive Manufacturing Problems

Simulation enabled the much faster and less-expensive approach that was used in this project. Croft engineers uploaded the original STL file into Additive Print. Additive Print provided graphical visualization of layer-by-layer stress accumulation and high-strain regions throughout the build. The software predicted distortion and residual stress of the as-built parts, including visualization of the differences between the original, undeformed geometry and the final deformed geometry, before and after removal from supports. These results provided diagnostic information that would not be possible otherwise. Also, the information was delivered in a small fraction of the time and cost that would have been required to build the part.

The simulation results revealed that the distortion was largely caused by the high-strength top section (a solid ring), which induced residual stresses in the weaker upper portion of the filtration mesh. The engineers tested



First attempt to produce the part by additive manufacturing resulted in considerable distortion.

ANSYS additive manufacturing simulation of the original design matched the distortion shown on the real part.

Croft engineers first simulated then built a prototype (shown here) of the part with the top section removed to diagnose the problem.

CAD model of redesigned part with supports incorporated into mesh

A combination of supports and distortion compensation made it possible to eliminate the distortion problem.

this hypothesis by simulating the filter with and without the top section. Without the top section, the results showed zero distortion. Croft engineers built the topless part to confirm these findings, and the results matched the simulation. Even though the top ring was essential to maintaining the structural integrity of the part, the knowledge that it was responsible for the distortion during the manufacturing process provided valuable input to the design process.

Meeting the Design Specifications

Croft engineers tried adding supports to the filtration mesh. These supports were attached to the top ring to increase the strength of the mesh area in the top of the filter. They tried using two helical supports with geometry designed to avoid restricting flow while not adding too much material weight and build time. They also changed the shape of the inlets to pentagonal to increase the inlet area while keeping the holes self-supporting and reducing the amount of support material required. When they simulated the new design, the results showed that distortion was considerably reduced but was still not satisfactory for this product.

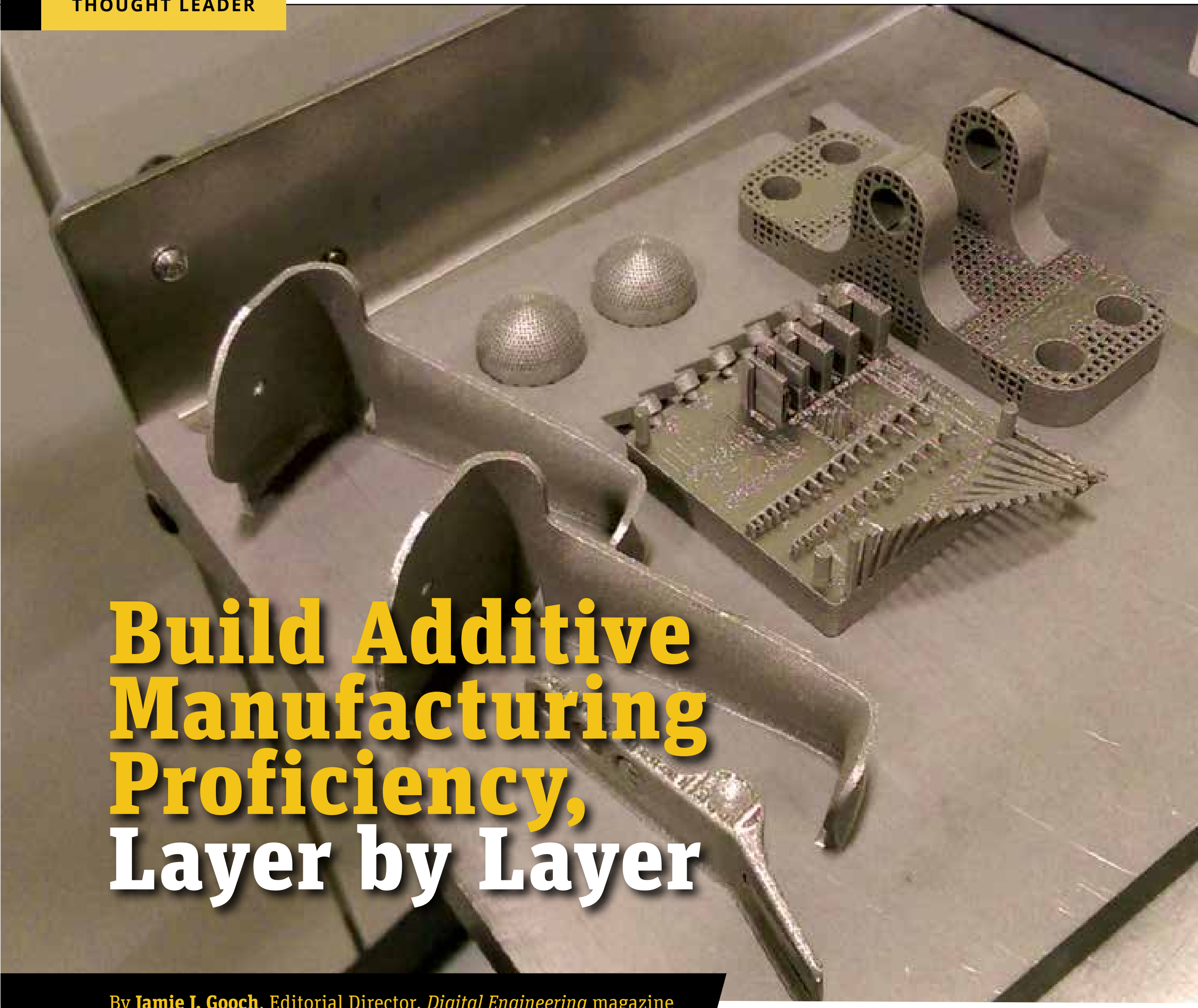
Engineers then leveraged the automatic compensation capability in Additive Print that adjusts the geometry of the build to compensate for the distortion. This feature moves the walls of the part in the opposite direction from that in which the distortion occurs to achieve the original design geometry. They simulated the distortion-compensated model and found that it overcompensated for the distortion, producing a small amount of distortion opposite to that found in the original geometry. So they used Additive Print to create a new geometry with the distortion compensation scaled to 0.75, 0.50 and 0.25 of the original amount. The simulation results for all these models still showed insufficient compensation for distortion. Finally, the engineers generated a model with distortion compensation scaled to 0.90. This design nearly eliminated distortion and met the design specifications.

“Croft Filters cut solution time in half and reduced prototyping expenses by about the same amount.”

Additive manufacturing allows companies to print parts that are impossible or very expensive to produce with traditional subtractive manufacturing methods. But organizations that are working to develop additive manufacturing into a real-world manufacturing process often must go through multiple trial-and-error processes to successfully generate high-fidelity parts. Simulation guides engineers to successfully create parts and processes at much lower cost and lead time than is required for trial and error. Croft engineers simulated the additive manufacturing process to determine the best part design and machine process parameters while minimizing the number of physical prototypes. The design of this part has been finalized, and it is moving to product launch.

Introduction to ANSYS Additive Print — Rapid Pre-Print Simulation for Metals
ansys.com/intro-additive-print

THOUGHT LEADER



Build Additive Manufacturing Proficiency, Layer by Layer

By **Jamie J. Gooch**, Editorial Director, *Digital Engineering* magazine

Photo courtesy Dr. Albert To, University of Pittsburgh

History has been measured by how our ancestors made their tools — from the Stone, Bronze and Iron ages through the Industrial Revolution and into the Information Age. Each breakthrough in toolmaking technology ushered in technological innovations across the spectrum of human activity. That is one of the reasons that people get so excited about additive manufacturing. It has the potential to make an impact on society in countless ways, some not even thought of yet.

Look a little more closely, however, and you'll find that the historical breakthroughs were sometimes millennia in the making. People were forging metal 6,000 years ago, but it took the invention of the steam engine to really jump-start the process. At less than 40 years old, additive manufacturing has expanded into industrial uses at a breakneck pace by comparison. Not a week goes by that we don't hear about new uses, techniques and/or investments regarding industrial additive manufacturing.

Picking up Steam

Many innovations have converged to propel additive manufacturing forward at such a rapid pace — materials, robotics and sensors, to name a few. However, the steam engine that really enables additive manufacturing to move out of research facilities and onto factory floors is software.

> **“Many innovations have converged to propel additive manufacturing forward at such a rapid pace — materials, robotics and sensors to name a few.”**

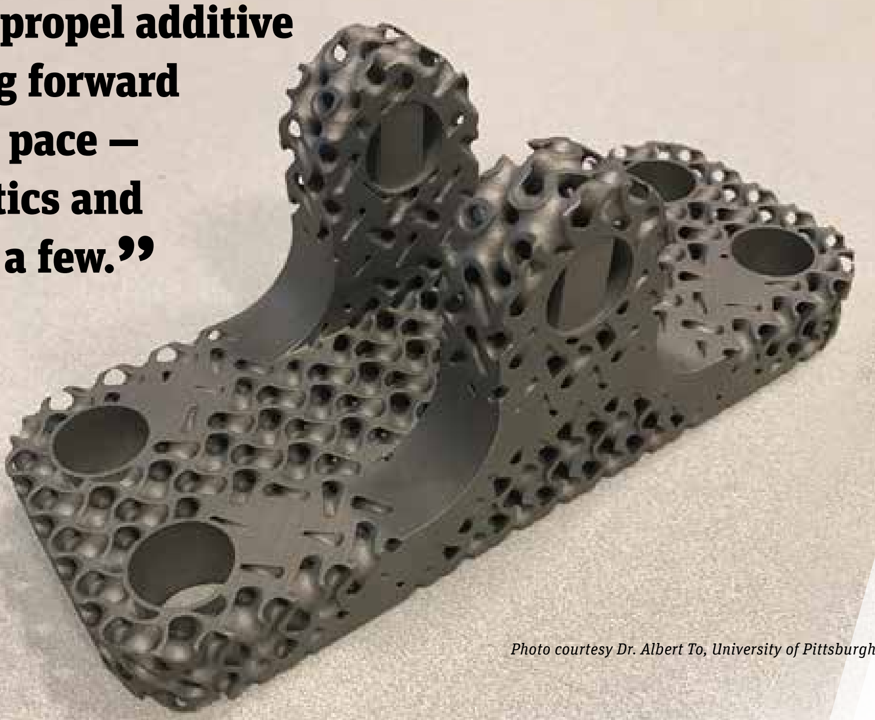


Photo courtesy Dr. Albert To, University of Pittsburgh

Designing for additive manufacturing requires a different mindset than for traditional manufacturing processes. From details like overhangs, support structure placement and part orientation to bigger decisions like whether additive manufacturing is even the right choice for a given application, what materials to use or how parts can be consolidated and optimized — it can be overwhelming.

Design engineering teams who have spent decades accustomed to the ins and outs of milling or injection molding might be inclined to stick with the status quo if they don't have the right tools and training. Or, even worse, they may decide to make an initial trial of additive manufacturing based on rumors of push-button production, only to be sorely disappointed and abandon their efforts.

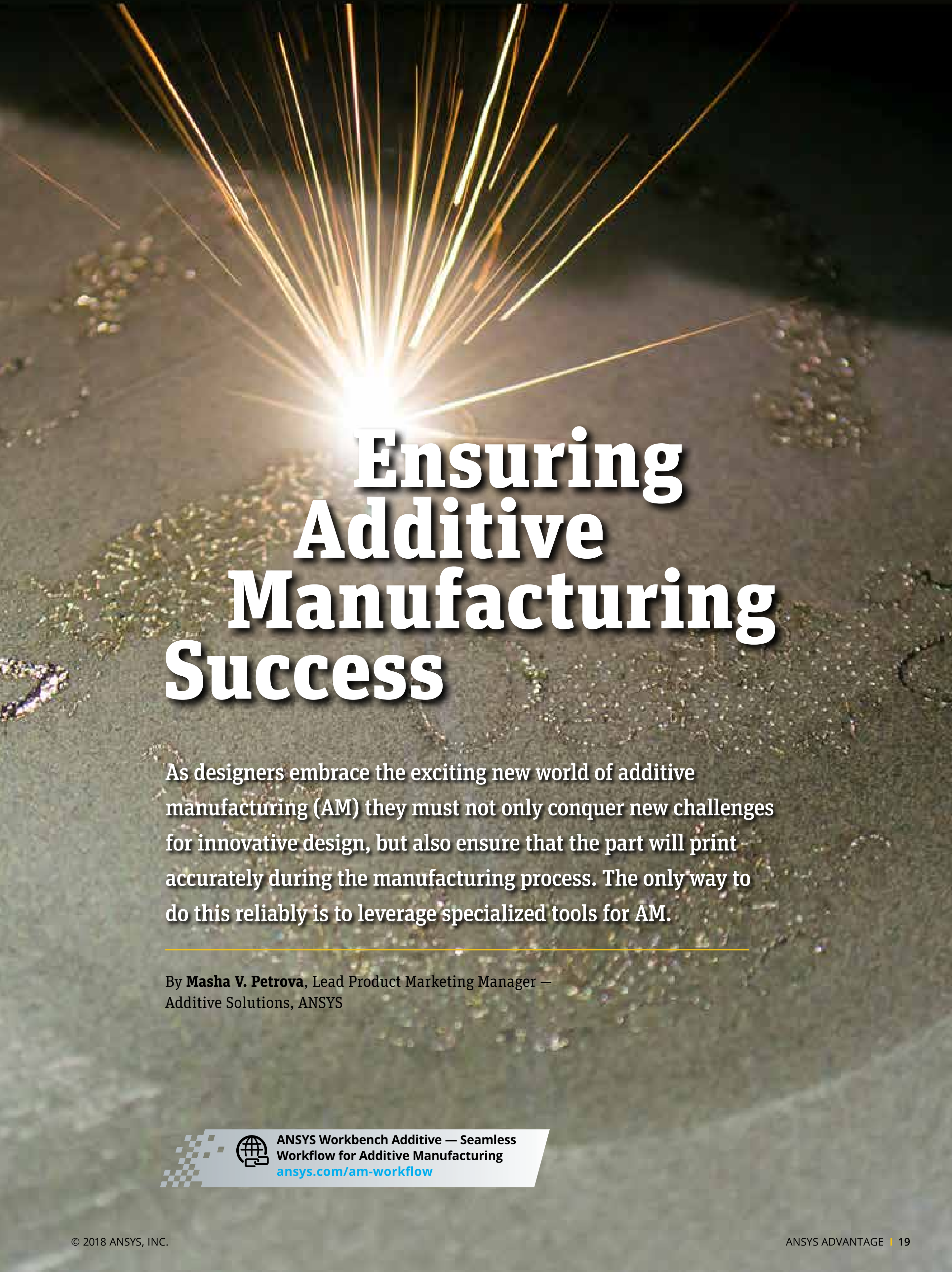
Make the Cultural Connection

Software is so important because it is how we connect to the hardware, make sense of the variables and fit additive manufacturing into existing product design, development and manufacturing workflows. Many voids in the additive manufacturing process have been filled with tools focused on preparing existing files, designing for additive manufacturing from scratch, determining when to outsource to a service provider, ensuring efficient use of print bed space, simulating specific additive processes, and understanding how design changes will affect a build.

There is still more progress to be made on the additive manufacturing software front before it rivals what is available for other manufacturing processes. However, we've turned the corner from design engineering teams asking "Why isn't there software to help me do this?" to "Which software should I choose to do that?"

Like a continuous build, the layers of additive software, hardware and number of people who know how to use them keep growing, bringing shape to its future. If you aren't one of those people, take another look at additive manufacturing. The progress made on the software layers in just the last few years may surprise you, and the progress that will be made in the next few years may leave you behind if you don't.

Gooch is editorial director of Digital Engineering *magazine (digitaleng.news), which is read by design engineering teams who want to learn about technologies to optimize the product design and development process.*



Ensuring Additive Manufacturing Success

As designers embrace the exciting new world of additive manufacturing (AM) they must not only conquer new challenges for innovative design, but also ensure that the part will print accurately during the manufacturing process. The only way to do this reliably is to leverage specialized tools for AM.

By **Masha V. Petrova**, Lead Product Marketing Manager — Additive Solutions, ANSYS

ANSYS Workbench Additive — Seamless Workflow for Additive Manufacturing
ansys.com/am-workflow

Poor execution can kill even the greatest ideas.

As additive manufacturing matures to a commercial-scale manufacturing process, we are watching the stuff of science fiction become reality. Bringing to life organic shapes that were previously impossible to manufacture, employing radically new materials with never-before-seen properties, and transporting a machine and some metal powder to remote corners of the world (or even the universe) to manufacture all kinds of complex components on demand are some of the promises of AM.

CHALLENGES TO AM SUCCESS

But there are challenges. Before we send an AM machine into space to help build an infrastructure to colonize Mars, a large problem must be addressed. Parts deform as they print. Specifically, during the powder-bed metal AM process temperatures oscillate as relatively cool metal is suddenly zapped by a laser followed by a relatively rapid cooldown, before being zapped again through a fresh layer of powder. This causes thermal stresses to build, which can cause the parts to deform, pull off the build plate or even explode inside the expensive metal AM machine.

> **"How do designers avoid the fate of having their great designs destroyed during the AM manufacturing process?"**

Design for additive manufacturing, DfAM, is a hot new field for designers. Through topology optimization and design exploration tools, the engineering design process is becoming decoupled from the spheres and blocks of traditional CAD. With the promise of AM, designers' creativity is being unleashed to leverage shapes that previously could only be found, for example, in the bending of tree branches or the veins of a butterfly wing. These shapes now appear in aerospace heat exchangers, automotive brackets and custom knee replacements.

Yet, this rapid growth provides more questions than answers. As eager designers, lured by the AM promise, are inspired to create wonderful new designs with organic channels and intricate manifolds, many do not realize that their great ideas might, through the complexity of the AM process itself, force them to redesign parts repeatedly in order to print parts that conform to spec.

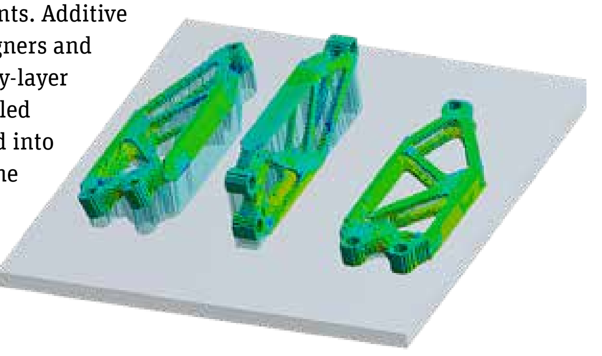
So how do designers avoid the fate of having their great designs destroyed during the AM manufacturing process? The answer is simulation.

If a designer who is creating a product for additive manufacturing has access to simulation tools that allow him/her to visualize whether the part will actually print accurately, before it is sent for manufacturing, the designer stays in control of his or her design and makes sure the design stays true to its form even through the printing process.

ANSYS Additive Print predicts displacement for a heat exchanger. Courtesy Additive Industries.

SIMULATION FOR ADDITIVE MANUFACTURING

Because every engineer works differently and wants tools that fit seamlessly into their workflow, ANSYS provides a number of solutions for additive manufacturing that take into account different requirements. Additive Print, a stand-alone solution, was created with DfAM designers and AM machine operators in mind. The Additive Print layer-by-layer metal powder bed simulation tool is key to eliminating failed builds and physical trial and error, and is easily integrated into designers' and AM machine operators' workflows. While the underlying solvers are sophisticated, the user interface is uncomplicated. Designers can import their CAD or STL files into Additive Print, run a simulation faster than printing a physical part, visualize what would happen to their design during the print process, and adjust their supports or designs accordingly.



ANSYS Workbench Additive

"Additive manufacturing is opening the doors of imagination for both designers and analysts."

Just like Additive Print, ANSYS Workbench Additive also simulates the metal powder bed printing process but within the familiar Workbench environment. It helps users to eliminate failed builds and to visualize deformation and thermal stresses during the print process. But unlike Additive Print, Workbench Additive was created for engineering analysts so they can remain within the ANSYS Workbench environment throughout the entire simulation process.

HOW IT WORKS

For example, an aerospace engineer might import a complex CAD geometry, consisting of thousands of parts, into Workbench, then clean the geometry by applying ANSYS SpaceClaim and set up a full analysis file, for either just one part or the entire assembly. The engineer can then run full transient heat-transfer simulation, full structural and/or thermal analysis to determine what kind of geometry changes are needed, all inside Workbench. He or she can also run a CFD analysis to see how geometry variations can affect pressure drop, for example. The engineer can also run topology or lattice optimization analysis, and then re-run any of the structural, CFD or modal analyses — all without leaving ANSYS Workbench.

Once the engineer determines that the part will perform as needed, he or she can run Workbench Additive to determine how the part will print. Is there thermal stress buildup? Is there deformation? Should the supports be adjusted or must the part be redesigned and reanalyzed? After the print simulation, post treatments like removal from the base plate and heat treatment can also be simulated — all inside ANSYS Mechanical. ANSYS Workbench allows engineers to perform fatigue analysis to see if the part or assembly (whether printed or manufactured traditionally) will hold up through wear and tear, and to perform a variety of optimization processes.

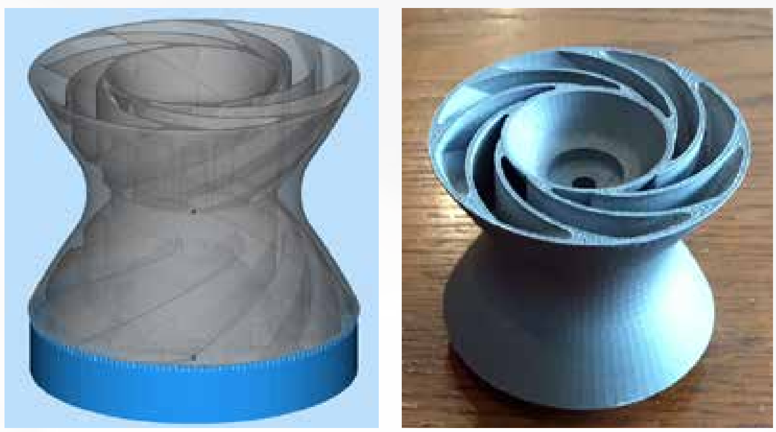
Additive manufacturing is opening the doors of imagination for both designers and analysts. Many thrilling design ideas will come to life in the upcoming years. Simulation will ensure that those ideas can survive the challenges of the additive manufacturing process so they can come to life.

Getting Metal 3D Printing Right the First Time with ANSYS Additive Print

As the benefits of additive manufacturing become increasingly apparent, organizations are seeking ways to improve processes for 3D printing. ANSYS channel partner PADT has long been in the forefront of additive manufacturing as part of a broad range of services for rapid prototyping. The PADT team has recently been working with ANSYS Additive solutions to ensure that customers can quickly receive additively manufactured parts that are viable immediately.

By **Eric Miller**, Principal and Co-Owner, PADT, Inc., Phoenix, USA

Metal additive manufacturing is one of the fastest growing sectors of manufacturing. According to the Wohlers Report, 2017 saw an 80 percent growth in metal system sales. Companies across industries want to leverage the speed and flexibility of 3D printing to create their metal components. The most common process is to build metal parts layer by layer with laser powder bed fusion during which a laser melts powdered metal, then that metal solidifies. However, this creates thermal stresses, and thermal stresses create distortion. The result, at best, is a part that does not match the CAD model within acceptable tolerance. At worst, because distorted parts interfere with the machine during printing, very costly machines can be damaged when the powder-smoothing blade hits portions of the parts that protrude from the powder.



ANSYS Additive Print confirmed that no additional supports were required for this part for a small gas turbine. The manufactured item verified the correctness of the part.

PADT purchased its first 3D printer almost 25 years ago and has been adding machines ever since. Six different additive manufacturing technologies in this area are offered to customers, and hundreds of parts are processed per month. PADT has been running one of the newer technologies, laser powder bed fusion for metals, for over a year. During that time engineers have viewed residual stress deflection issues firsthand. Some parts are not badly distorted, but others curl up like potato chips. In most cases, the team designs thin metal structures as supports under overhanging features to hold the part down until it is heat treated to alleviate those stresses. But PADT was only speculating on what supports were necessary and often overdesigned them. The team now uses ANSYS Additive Print to optimize supports, compensate for distortion and avoid blade crash. It has been a real time saver.

The team first used ANSYS Additive Print on a part from a customer, Monarch Power Corp., which is developing innovative solar-powered products so that people can generate their own power. One of their new products is a small gas turbine with a centripetal spiral vane compressor, internal combustion chamber and centrifugal spiral vane expander. It is ideal for additive manufacturing because all these elements can be printed together along with a built-in axial flux electric generator. It is self-supporting, there is no overhanging geometry, and the outside surface holds all the internal geometry in place, so it only needs supports on the bottom of the part. ANSYS Additive Print predicted minimum distortion and no need for supports. Following the recommendations of Additive Print, PADT built the part with no supports. The actual build verified the ANSYS model. PADT saved the customer time and materials by avoiding over-constraint of the part by unnecessary supports.

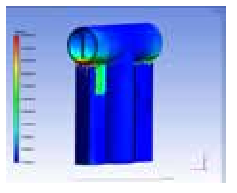
When designing a T-tube for additive manufacturing, the alternative to simulation is trial-and-error, which would have led the team to the same conclusion after spending several weeks and tens of thousands of dollars in printing, post-processing and engineering expense. Trial-and-error also results in wasted metal and damaged powder blades. PADT was easily able to verify that the model was good in the turbine model, and then determine the geometry to correct printing errors for the T-tube.

The simulation process was simple and intuitive, and a manufacturing intern did all the modeling in ANSYS Additive Print. Additive Print will be part of future metal 3D printing projects to save iterations and material, and deliver accurate final parts to PADT customers sooner. Λ

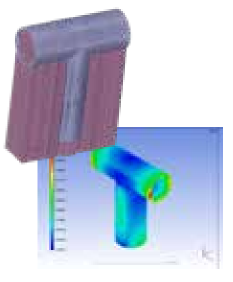
The work mentioned in this article was done by Paraic O'Kelly and Anna Hayes in PADT's Manufacturing Technology department.

ADDITIVE MANUFACTURING OF A T-TUBE

The team decided to really put ANSYS Additive Print to the test by simulating and manufacturing a T-tube model that PADT has been making for decades, to test support structures and accuracy for plastic and metal 3D printing.



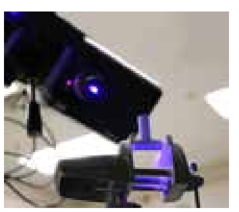
After generating supports using PADT's standard 3D printing pre-processing tool, the team performed a quick assumed strain analysis in Additive Print and determined that the model was not being held properly. The first layers at the bottom of the horizontal tube distort significantly so that if the part had been printed, the layers would probably pull off the support and crash the machine.



PADT staff used ANSYS Additive Print to design the supports. The software predicted a distortion of 0.4 mm vs. the 3.0 mm with the standard supports.

The distortion compensation capability in ANSYS Additive Print was then used to calculate local distortion and modify the geometry so that the final printed shape would be even closer to the desired dimensions.

The part (including the supports) was printed in 17-4PH stainless steel on a Concept Laser MLab laser powder bed fusion system.

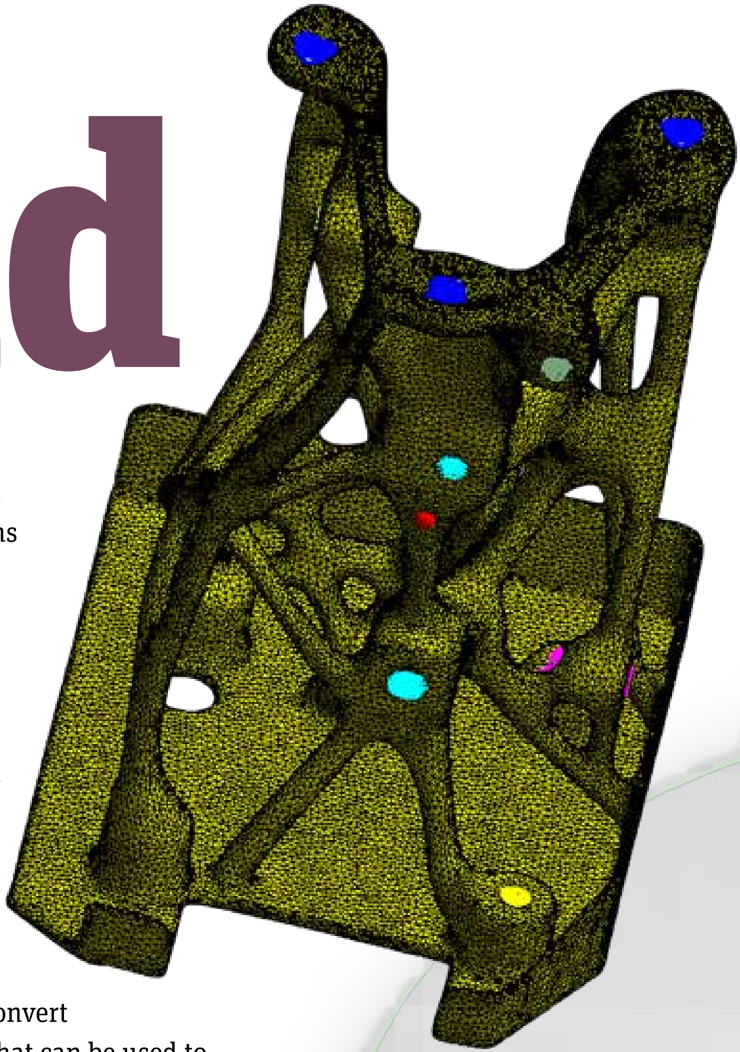


Using a ZEISS structured light scanner, the PADT scanning team inspected the part with the supports removed. The measurements revealed approximately a 0.38 mm deviation from the nominal CAD model, which, for a part with this much distortion potential, was very good.

When the scan results were compared to the final geometry, it was revealed that the surface roughness from the support material removal is the cause of most of the deviation, not thermal distortion. In areas away from the surface roughness of the support attachments, the distortion is only about 0.13 mm, showing that the optimized supports and distortion compensation from ANSYS Additive Print produced a final printed part well within acceptable tolerances.

The printed part >

Filling a Void



Metal additive manufacturing enables production of complex metal parts that meet mechanical property specifications without the need for costly tooling. In addition, parts can be made in small batches or even manufactured on a "one-off" basis. Computed tomography (CT) scanning can be used to identify defects such as voids or inclusions that can occur in parts created through metal additive manufacturing, but in the past there was no way to determine how these manufacturing byproducts might affect performance. A new process has been developed to convert CT images into finite element models that can be used to predict the mechanical properties of as-manufactured parts.

By **Matthew Nixon**
Applications Engineer
David Harman
Account Manager
Simpleware Product Group
Synopsys Exeter, UK and
Julien Uzanu
R&D Engineer
Jérémie Dhennin
CEO
ELEMCA, Labege, France and
Jean-Michel Desmarres
Material Expert
CNES, Toulouse, France

Materials and processes used to produce critical components for aerospace and defense applications must first be formally qualified to demonstrate that these components will function as expected. The increasing use of metal additive manufacturing creates validation challenges because the incremental process through which parts are built up stepwise, one layer at a time, creates the potential for inconsistencies not seen in traditional manufacturing methods. Tiny defects are often detected with CT scanning, which raises the question — what is their impact on the performance of the part? A new method for simulating the performance of an as-manufactured part based on CT scan data is being used to validate the sun assembly sensor (SAS) support in the TARANIS spacecraft.

More than two thousand storms are permanently active in the Earth's atmosphere at altitudes between 20 and 100 kilometers. These transient luminous events, each of which produces 50 to 100 lightning bolts per second, were discovered relatively recently, so current knowledge is limited to observations of light emissions from the ground. The

> “A new method for ***simulating the performance*** **of an as-manufactured part based on *CT scan data* is being used to validate a support in the *TARANIS spacecraft*.”**

TARANIS microsatellite from Centre National d’Etudes Spatiales (CNES) — the government agency responsible for shaping and implementing France’s space policy — will observe these stormy regions from an altitude of 700 kilometers to better understand their effect on the earth’s atmosphere, ionosphere and magnetosphere.

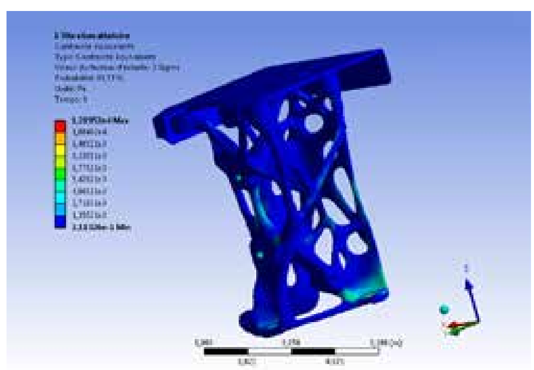
The attitude and orbital control system (AOCS) of the TARANIS microsatellite will precisely determine and control the orientation of the satellite. The AOCS uses the SAS to detect the position of the sun. The SAS support provides the sensor with 180-degree clear views. It is mounted to a device that swivels the sensor to maintain a view of the sun regardless of the satellite’s orientation. The position of the sensor in the payload, coupled with the lever effect of the support, makes the sensor very sensitive to the dynamic environment generated by the rocket during the launch phase. Thus, the most important structural requirement of the support is that it be stiff enough to maintain primary modal frequencies greater than 350 Hz. Modal frequencies below that value could potentially interact with the launcher and spacecraft main modes and damage the sensor.

TARANIS satellite will study high-altitude storms.

CAD model of sun assembly sensor support

ADDITIVE MANUFACTURING SAVES WEIGHT

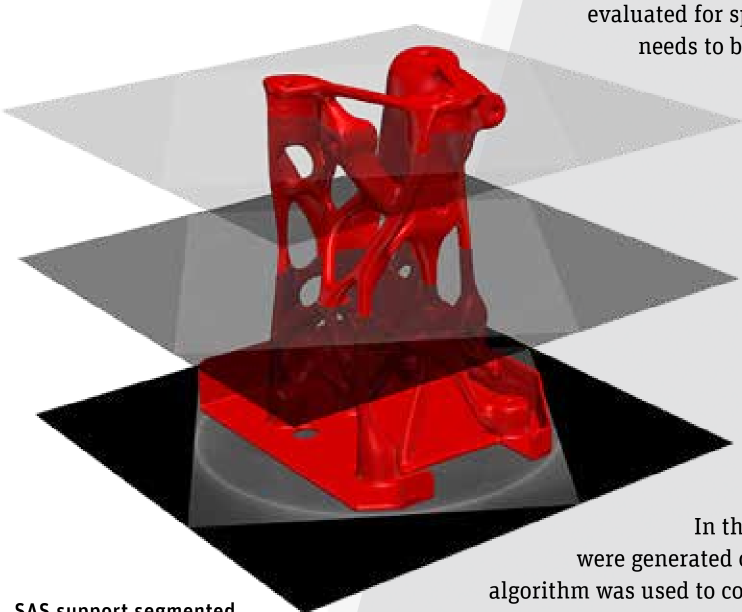
Additive manufacturing is expected to be the manufacturing method to produce the SAS support because it eliminates the design-for-manufacturability constraints of conventional subtractive manufacturing processes. Engineers used topology optimization to fully exploit the design freedom provided by additive manufacturing by starting from blank space and iterating to an optimized design while changing both the basic shape and the dimensions of the part. The result is a design that reduces manufacturing and assembly costs by reducing the number of components within the support from 11 to one. At the same time, the weight of the support was decreased by 30 percent to allow for an equivalent increase in the spacecraft payload.



Von Mises stress plot created by finite element analysis of model based on CT scanning of physical part in ANSYS software

The ANSYS Vision for Simulation-Driven Product Development in Additive Manufacturing
ansys.com/am-vision

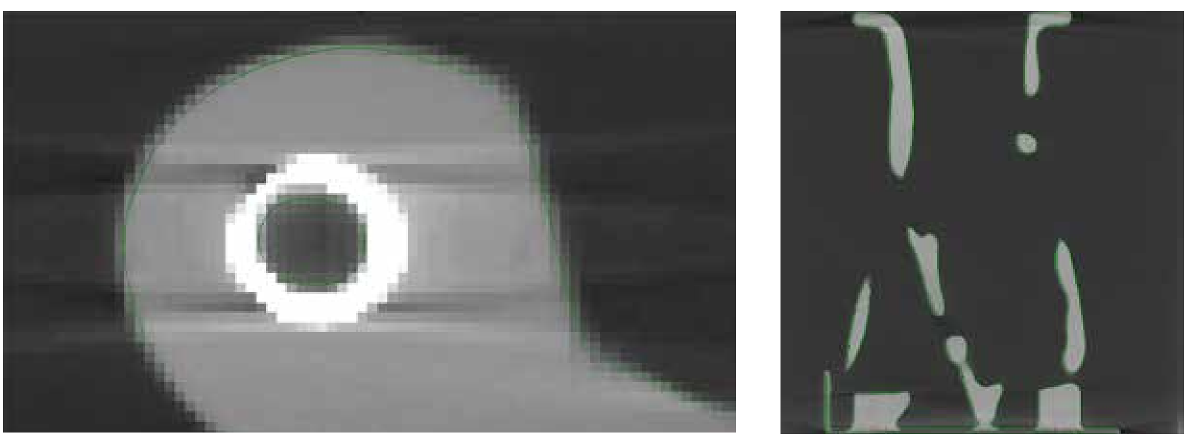
It cannot be assumed that parts made from additive manufacturing are free of internal defects. Three-dimensional (3D) printed parts are just beginning to be evaluated for spacecraft applications, so their reliability needs to be proven beyond a shadow of a doubt since there will be no way to perform repairs in space. Today, CT scanning is the most common way to assess the compliance of parts produced by additive manufacturing because it can detect internal flaws without destroying the part. Until recently, engineers could only detect flaws with CT scanning; they were unable to quantify the impact of these flaws on the properties of the as-manufactured part.



SAS support segmented from CT scan data in Simpleware software

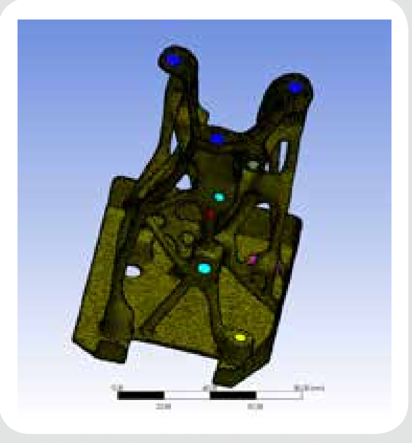
SIMULATING THE AS-MANUFACTURED PART

In this project, a total of 1,300 CT images were generated of the SAS support, and a mathematical algorithm was used to combine these images to reconstruct the part volume. Voids were visible as dark gray areas and inclusions as light gray areas in the 3D scan data. In addition, titanium screws in the part were visible as light-colored artifacts. Working with the scan data, Simpleware and ELEMCA engineers used Simpleware's ScanIP image processing platform to import the scan data. Employing ScanIP, they segmented the structure by detecting voxels (values on a grid in 3D space that are analogous to pixels in 2D space) by setting threshold values that differentiated the part from its surroundings and excluded the latter. Manual segmentation methods were used to further enhance the scan data by, for example, identifying the screw holes and removing the screws. The geometry was meshed using Simpleware's FE module to automatically produce a coarse mesh while enhancing details where gradients were expected to be high. The final model, which consisted of about 450,000 elements, was then exported as a native ANSYS model for finite element analysis. The boundary conditions set up in ANSYS Workbench were the same as the



Segmentation of the SAS support in Simpleware software

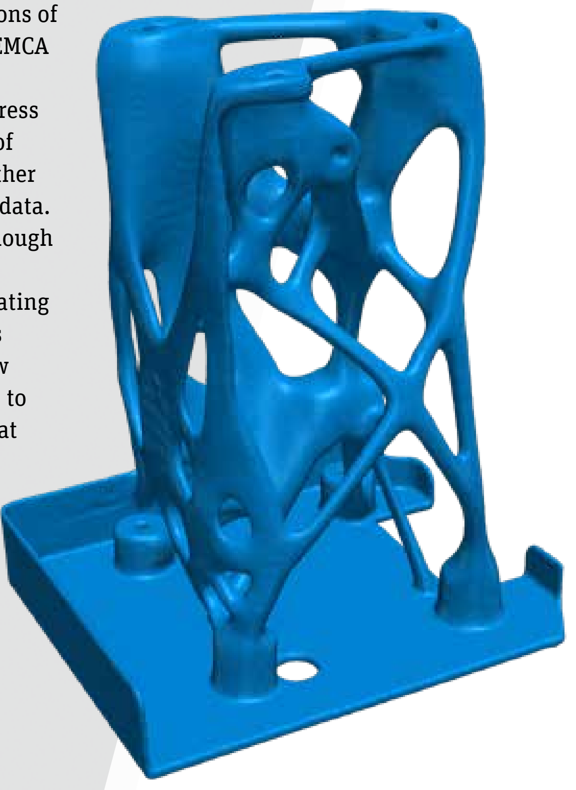
“CT scanning can be combined with *finite element analysis* to provide a structural simulation of the as-manufactured part that provides a more *realistic prediction* of part performance.”



ANSYS model generated in Simpleware FE module

structural simulation that had been used to create the original design. They included a fixed support at the base, a point mass for the support and a point mass at the connectors representing the SAS. ANSYS Mechanical results showed that the design produced by additive manufacturing met the main flight requirement with modal frequencies well below the critical value. Von Mises stress values for the as-manufactured part were slightly less than the values that had been obtained in structural simulations of the CAD model. ELEMCA engineers attribute this reduction in stress to the elimination of screws and a few other minor components from the model produced from the CT scan data. Importantly, the inclusions and voids in the part were small enough to have an insignificant impact on performance.

Simulation played an important role in the process of validating this part, which is currently undergoing physical testing and is expected to be integrated into the mission. It demonstrates how CT scanning can be combined with finite element (FE) analysis to provide a structural simulation of the as-manufactured part that provides a more realistic prediction of part performance. This advancement should aid in the difficult task of qualifying parts produced by additive manufacturing for critical aerospace and defense applications. By using Simpleware software to develop the as-manufactured model and ANSYS software to perform virtual testing, ELEMCA achieved the potential of additive manufacturing to produce complex mechanical parts with less weight and superior mechanical properties while avoiding tooling expense.



SAS support segmented from CT scan data in Simpleware software

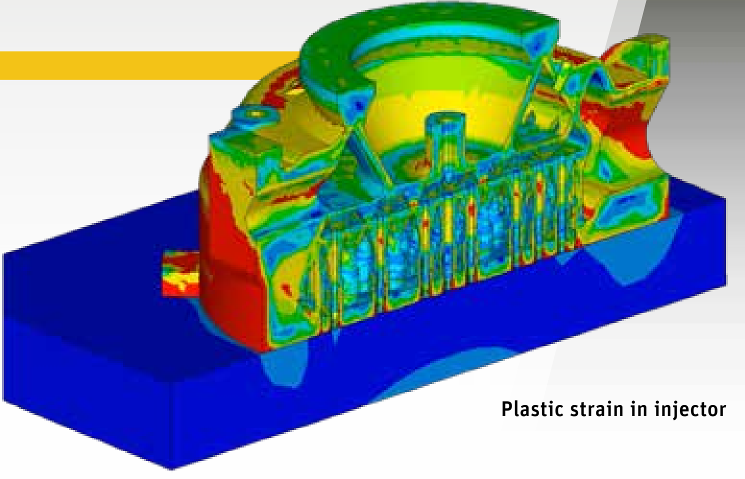
Reference

Uzanu, J.; Dhennin, J.; Nixon, M.; Harman, D.; Desmarres, J-M. Quality Control of a Metallic Additive Layer Manufacturing Part Thanks to X-ray Computerized Tomography and Finite Element Modeling, 14th European Conference on Spacecraft Structures, Materials and Environmental Testing, Toulouse, France, September 27–30, 2016.

Qualifying Additive Manufactured Rocket Parts with Simulation

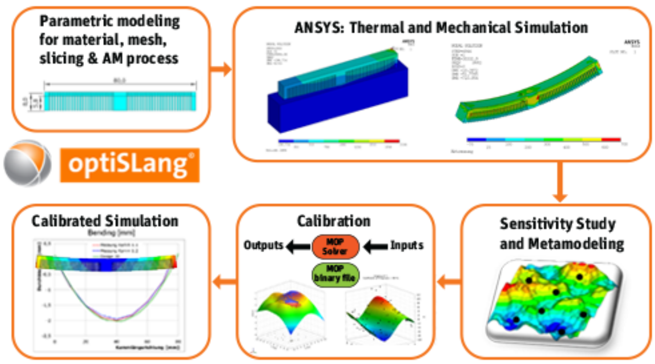
As the aerospace industry moves to implement additive manufacturing, it must validate that components will survive in an environment where a single failure in a launch vehicle could force termination of a mission. When introducing a new production technology, because many parts must be produced and verified until target quality can be achieved, the traditional trial-and-error validation process is very time-consuming and expensive. ArianeGroup used ANSYS and Dynardo software to create a simulation-based workflow that predicts part quality and has the potential to significantly reduce the process time required by the traditional method.

By **Dieter Hummel**
Thermomechanics Engineer
ArianeGroup GmbH
Ottobrunn, Germany and
Roger Schlegel
Director of Consulting
Dynardo GmbH
Weimar, Germany



Plastic strain in injector

Avoiding mission failure is the number one requirement for a launch vehicle. Each failure sacrifices the launch cost of about $150 million and the loss of a satellite that might cost hundreds of millions of dollars and take years to rebuild. Between April 2003 and December 2017, ArianeGroup's Ariane 5 heavy-lift launch vehicle successfully delivered 82 consecutive payloads into geostationary transfer orbit (GTO) or low Earth orbit (LEO) without a single failure. ArianeGroup is currently developing the next-generation Ariane 6 launch vehicle with similar performance to the Ariane 5 but with lower manufacturing costs and launch prices. Metal additive manufacturing is being used in the Ariane 6 to reduce manufacturing cost and lead time, and to decrease part weight and the space required to accommodate it.



Workflow uses ANSYS Mechanical and ANSYS optiSLang to calibrate simulation models.

In the company's liquid propulsion engineering cluster, one department focuses on combustion devices, a generic name for all engine components that handle hot gases, such as gas generators, power units and main thrust combustion chambers. ArianeGroup qualified the first parts for additive manufacturing using an expensive trial-and-error process that involved building prototypes and testing them to determine their performance. The thermomechanics team within the combustion device department has recently developed an automated workflow using ANSYS Mechanical to simulate the additive manufacturing process. During the development process for new components, engineers identify risks during the printing process by leveraging simulation to predict temperature, stress and strain evolution. ANSYS optiSLang allows the team to automate the process and calibrate the model to optimize manufacturing process parameters at a fraction of the cost of the current hardware trial-and-error method.

Previous Validation Process

The powder bed metal additive manufacturing process works by placing a thin layer of metal powder on a build plate. A laser sweeps the build plate to selectively melt tiny sections of the powder to form one layer of the part. As each section cools, it contracts, but the solid underlying layers resist these contractions, generating residual stresses. These residual stresses can generate distortions in the finished part (plastic strain) and, in the worst case, cracks that often cannot be detected with inspection because they are hidden by other sections of the part. Combustion devices are critical to the success of the mission, so switching to a new manufacturing process requires proving that the new process is free of cracks and other defects.

Before approving additive manufacturing parts for inclusion in the Ariane 6, ArianeGroup engineers must understand the process, determine the effects of key process parameters on part quality, and develop a manufacturing process that reliably allows them to meet final quality requirements, including the variability of each process parameter.

Simulating the Additive Manufacturing Process

To develop a workflow to increase the speed and reduce the cost of validation, ArianeGroup and Dynardo engineers first created a model of a relatively simple part. They simulated the additive manufacturing process with ANSYS Mechanical finite element analysis software and developed an ANSYS Parametric Design Language (APDL) script that mimics the metal additive manufacturing process by slicing the entire structure into individual layers. The elements of the printed layer are then activated with the EALIVE command, which

Additive Manufacturing Simulation Made Easier

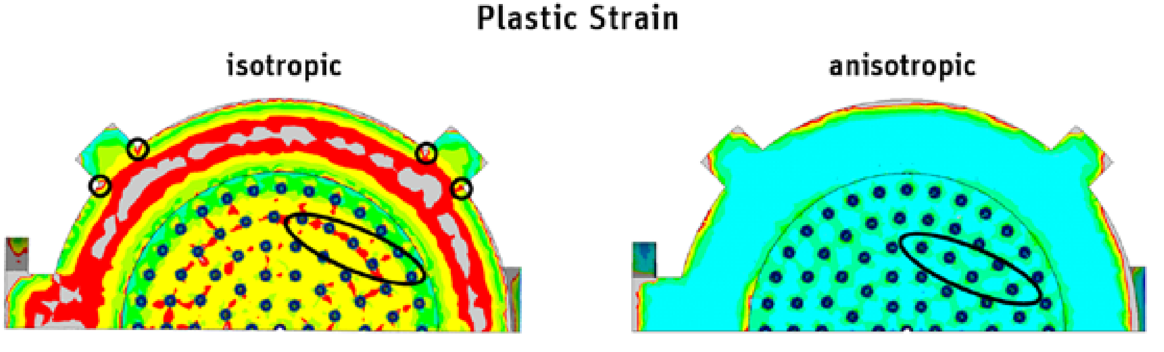
Recently, ANSYS has released ANSYS Additive Suite, which reduces the need for APDL script development by users, supports the parameterization of the models and optimizes solver settings. Learn more about these capabilities in the article "Ensuring Additive Manufacturing Success."

Ariane 6 rocket

sets their temperature at the melting temperature of the material used to produce the part. Different variations of this script either activate the entire layer at once, activate rectangular elements on a layer in a step-wise fashion, or sequentially activate angular swathes across the layer. The elements are then allowed to naturally cool, and the residual stresses are tracked in each element. Another layer of elements is then activated in the model in the same way as the preceding layer. The script simulates the complete process of building the part and tracks the residual stresses and deformation of each element.

a complete layer, one rectangular element at a time of various sizes, or an angular swatch across the layer), the time until melting of the next partial layer and the time until placement of the next powder layer.

Measurement of the manufactured material revealed anisotropic deformation and strength behavior, so engineers used Dynardo's multiPlas, a custom anisotropic multisurface elastoplastic material model in ANSYS Mechanical, to match this anisotropic behavior, and incorporated it into the additive manufacturing model. Comparing isotropic and anisotropic elastoplastic material models, the team determined that the lower yield and ultimate strength



Comparison between isotropic and anisotropic elastoplastic material models. Anisotropy has a major impact on plastic strain forecast.

Calibrating the Simulation Model

To prove the quality of the simulation model, test structures were produced and the model calibrated to measured deformation and residual stresses. In the calibration process, the variation space of the material parameter, the process parameter and the discretization parameter is scanned by a design of experiment (DoE). From this, a metamodel of optimal prognosis (MOP) is generated by optiSLang. This metamodel shows how process variability affects the results. The MOP is then used to calibrate the simulation model parameters to match the results of physical measurements on the part. Important parameters used in the calibration were the element size on the x, y and z axes, the laser path (activating

in the normal direction (between 80 percent and 90 percent of the strength in the in-plane direction) has a very important effect on the evolution of plastic strains. Employing this anisotropic material model, the finite element model was calibrated to predict the physical build to a high level of accuracy.

Once the process parameter at the test structure was calibrated, the simulation workflow was ready to forecast deformation, stresses and cracks of the part to be qualified. ArianeGroup and Dynardo engineers simulated the process of building a more complex part,

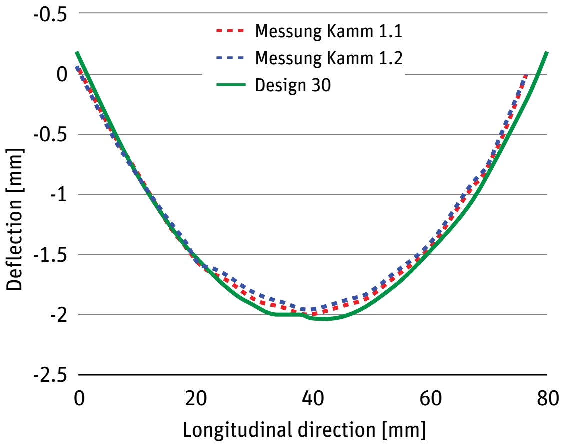
ANSYS optiSLang
ansys.com/optislang

an injector for a development prototype. The finite element model had 1,065,000 nodes and 620,000 quadratic volume elements. It required 7 hours for thermal analysis and 32 hours for mechanical analysis on a personal computer with 4 central processing units. The forecast using anisotropic material models was an excellent match to the measurements of the printed injector.

Optimizing the Part Geometry and Manufacturing Process

Next, engineers extended the workflow to investigate the effect of part geometry variation and key additive manufacturing process parameter variations on residual stress, plastic strain and distortion of the finished part. They created a fully automated workflow that identifies the sensitivity of part quality to each design and process parameter incorporated into the DoE used to build the MOP. The workflow can optimize the part geometry and the additive manufacturing process at the same time.

The exceptionally high cost of a failure in the extremely competitive aerospace industry makes it essential to perform a thorough validation process before adopting new technologies. In the past, this has meant a long trial-and-error process to validate new manufacturing processes. Simulation can be combined with a much smaller volume of physical testing to provide fast qualification and insertion of new technologies without sacrificing mission safety. For example, this new workflow drastically reduces the time required to validate a new part, potentially making it possible to optimize the part geometry and additive manufacturing process with only two builds, one to validate the simulation model and the second to validate the optimized part design and process. ArianeGroup engineers are planning to use this process to reduce the time and cost required to validate parts for the new Ariane 6 launch vehicle.



Deformation predicted by calibrated simulation model closely matches physical measurements.

The Shape of Things to Come

From its beginnings more than 30 years ago, additive manufacturing has come a long way, capturing the public's imagination and gaining growing interest from manufacturers. However, this technology still holds enormous unrealized potential — and simulation will play a critical role in delivering on that potential.

By **Brent Stucker**
Additive Manufacturing Director
ANSYS

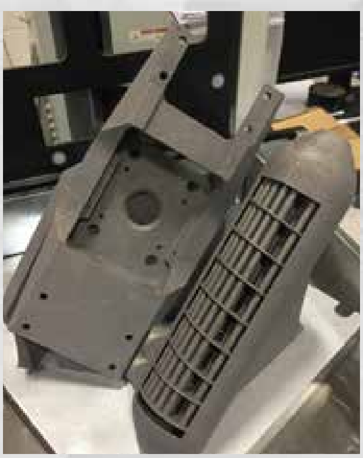


Photo courtesy Dr. Albert To, University of Pittsburgh

Twenty-five years ago, I was a Ph.D. student working on materials and production concepts for an emerging idea called additive manufacturing, or AM. Not one of my friends or family members understood what I was doing. Today, the term "3D printing" has entered our collective consciousness, and I no longer have to explain my job to anyone. Sales of metal 3D printers grew by 80 percent in 2017. The excitement around additive manufacturing is palpable.

But, while a few pioneering companies are leveraging the power of AM to mass-produce parts, for the most part, the potential of additive manufacturing remains unrealized.

There are a number of practical reasons for this. The equipment and materials can be cost-prohibitive for many companies. It can be frustratingly difficult to design products and define machine parameters for those just investing in AM technologies, and there is a shortage of professionals with AM experience. Printing mistakes are expensive, time-consuming and all too commonplace as companies struggle to get up to speed.

SIMULATION: MAKING THE VISION ACHIEVABLE

I believe engineering simulation holds the key to making 3D printing feasible, attainable and affordable for more and more companies. That's why I joined ANSYS.

Simulation significantly reduces the costly trial-and-error process that characterizes AM for so many businesses today. Instead of risking expensive powders, precious machine capacity and costly development hours on trial runs, companies can predict the results of their printing runs before the AM machine is turned on. They can identify areas of thermal or structural stress in the virtual world, and modify their designs to eliminate real-world shape distortion during printing. This is a game changer.

Via simulation, materials scientists can test their compositions and fine-tune them for not only real-world product usage, but also for the physical environment of 3D printing. Analysts can similarly predict the performance of their products, including geometric deformations, when subjected to production stresses and real-world operating environments.

After the design is handed off for manufacturing, product designers and machine operators can apply simulation to make adjustments that maximize printing results. Production surprises are minimized and risks are reduced — making the benefits of additive manufacturing much easier to achieve, profitably and reliably.

A CASE IN POINT: PARTS CONSOLIDATION

What exactly can simulation help accomplish? Consider the promise of parts consolidation. Many of the headlines around 3D printing have focused on the technology's ability to create a single, consolidated part, instead of 12 separate parts that are manufactured individually, then mechanically joined together.

Perhaps the most talked-about example is GE's revolutionary single-part nozzle for its jet engines — but today many businesses are exploring the idea of making single, highly complex shapes via additive manufacturing. Not only can parts consolidation save millions of dollars in production and materials costs, but it can also drastically improve product performance by reducing overall weight, eliminating vulnerable physical joints and avoiding system integration issues.

> **"For the most part, the potential of additive manufacturing remains unrealized."**

Yet, for engineers, parts consolidation is a risky proposition. Single-part geometries are necessarily complex, typically including complicated topologies, intricate lattices for internal support and new microstructures within their materials compositions. They typically require a custom-engineered framework (support structures) to provide structural integrity during the actual printing process.

Engineering these parts, building support structures, subjecting them to the rigors of AM, then — if all goes well — conducting physical testing is a process characterized by high complexity and a high risk of failure at every stage. With simulation, parts consolidation shifts from an unachievable vision to a practical reality — because all these activities take place in a risk-free, cost-effective virtual design space.

ANSYS: DEMOCRATIZING ADDITIVE MANUFACTURING

Armed with simulation capabilities, more and more companies will be able to capture the enormous potential of additive manufacturing, including parts consolidation, in the near future.

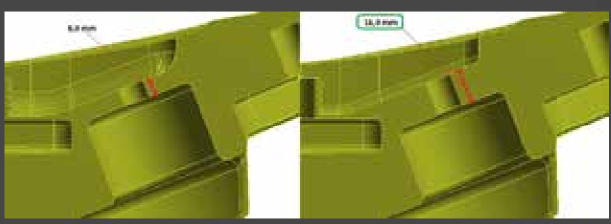
Today, metal 3D printing is seen as the domain of a few select businesses, and human expertise is in high demand as companies fight for skilled people to lead their additive manufacturing efforts. With a complete portfolio of simulation solutions for AM, ANSYS is equipping people across the company to become experts in 3D printing — making this technology accessible to more companies and even smaller businesses.

From materials scientists and physics analysts to shop-floor machine operators, ANSYS is committed to democratizing AM simulation and making 3D printing accessible to just about every business. It's a concept we're strongly committed to, because we believe simulation will cover the last mile in the continuing journey to make additive manufacturing commonplace across companies and industries. As director of additive manufacturing at ANSYS, I have had the opportunity to take 25 years of experience in AM and bring it to the world on a global scale. I hope to empower future generations of designers, engineers and creators to take AM to the next level using simulation.

Speedy, Lightweight MOTORCYCLE DESIGN

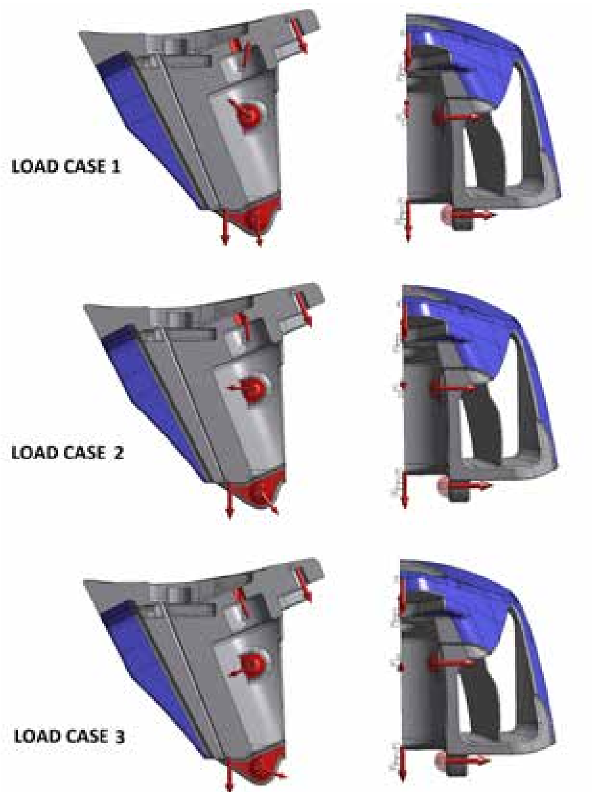
To achieve its amazingly light weight, the Vins Duecinquanta motorcycle uses a carbon fiber composite for its monocoque frame, rims, fork and bodywork. The aluminum frontal node is at the heart of the motorbike, sitting under the handlebars and connecting to the engine, frame, gas tank, radiator and suspension. Asotech engineers used ANSYS Mechanical topology optimization to develop an optimized design while changing both the basic shape and dimensions of the part to reduce its weight by 56 percent. Engineers then used ANSYS Mechanical fatigue analysis to achieve the product integrity balance needed to ensure that it will not fail under repetitive stress over time.

By **Davide Mavillonio**
Simulation Engineer
Asotech srl
Reggio Emilia, Italy



Using ANSYS structural analysis, the shape was altered to fix structural problems.

In its review of the new motorcycle, *New Atlas* said "The Vins Duecinquanta (250) is focused on weight reduction to a degree we've never seen before in a road bike." With a 60-horsepower engine and a curb weight of 209 lbs (95 kg), the new bike, which costs 40,000 euros (US$49,621), goes 120 mph (299km/h) while meeting the latest emissions laws. A significant portion of that weight reduction was achieved by Asotech engineers who used ANSYS Mechanical topology optimization to reduce the weight of the frontal node from 40 lbs (18 kg) to 18 lbs (8 kg). They also used ANSYS Mechanical fatigue analysis to ensure that the node meets Eurocode fatigue life requirements.



Load cases analyzed with structural simulation

High-End Performance Motorcycle

The Duecinquanta uses an electronically injected 90-degree V-twin, two-cylinder, two-stroke engine. The radiator is aerodynamically integrated with the bike, so incoming air flows over the radiator and back through the hollow frame where it exits through the tail and swingarms. The Duecinquanta Competizione, the racetrack version, reduces the weight even further to 187 lbs (85 kg) by removing equipment required for street use. It delivers 80 horsepower and provides a top speed of around 149 mph (240 km/h). The racetrack version costs 50,000 euros (US$62,029). Vins is planning to build 20 to 30 of the new bikes per year.

The Vins engineering team is composed primarily of Ferrari alumni who have expertise in working with carbon fiber composites. Because the frontal node is one of the most critical metal components of the bike, Vins sought out the assistance of Asotech, a leading Italian mechanical engineering company with 110 engineers who deliver more than 200,000 hours of services each year and a focus on the automotive, motorcycle, amusement park and automated machinery markets.

The traditional approach to designing this component would have been to start with a regular solid shape that provided the required mounting surfaces. Then engineers would have simulated the design and looked for low-stress areas where material could be removed. Exploring designs one by one and manually varying their dimensions in this manner could have generated considerable weight savings, but the time required would be prohibitive. Even then, engineers would not have been able to reduce weight to meet their goals.

The frontal node sits at heart of the bike.

Topology Optimization Minimizes Weight

Asotech engineers addressed this challenge by using ANSYS topology optimization, which is integrated with ANSYS Mechanical structural software. Vins engineers provided four load cases for the frontal node: 1) engine, passenger and lateral static loads; 2) engine, passenger and lateral static loads plus loads related to a moderate bump in the road; 3) engine, passenger and lateral static loads plus loads related to a maximal bump in the road; and 4) a fatigue stress state obtained by combining the three previous load cases. Asotech engineers then defined the features that must be maintained in the final design, such as the outer boundaries and mounting surfaces. They assigned an optimization objective to minimize the weight of the part while holding stress to a specified maximum value based on the material properties.

Asotech engineers then executed the topology optimization, which ran for six hours. Engineers examined the resulting design and discovered areas where it could be improved by changing some geometrical constraints.

> **“Asotech engineers addressed this lightweighting challenge by using ANSYS topology optimization, which is integrated with ANSYS Mechanical structural software.”**

Frontal node

They made these changes and ran the optimization again, this time starting from the previously optimized design. Engineers performed several more iterations — modifying the constraints and rerunning the optimization from the previous starting point — until they were happy with the design.

The Asotech team then imported the topology density distribution into ANSYS SpaceClaim Direct Modeler (SCDM) and used it to tweak the final design. SCDM makes it easy to edit and optimize complex models that often result from topology optimization. It enables users to seamlessly add or remove geometry, smooth rough faces or shrink-wrap sections of a model to remove unwanted features and characteristics.

Results of the ANSYS topology optimization

Fatigue Analysis Ensures Durability

Asotech engineers simulated the resulting design in ANSYS Mechanical to confirm that it could withstand the static loads specified by Vins. The engineers then used ANSYS fatigue analysis software to calculate high-cycle fatigue safety factors based on the Eurocode structural design standard. They imported the static stresses from the fatigue model, and combined the results with a material model and a description of the repetitive loading that the product is expected to undergo during operation. The ANSYS fatigue module captured the data, data flow and parameters, and performed a comprehensive fatigue analysis using the stress-life approach on the fatigue load case. The fatigue analysis showed that the design exceeded the 2-million-cycle fatigue life requirement by withstanding 5 million cycles. Based on these results, engineers ran another cycle of topology optimization that further reduced the weight of the part slightly.

The founder of Lotus cars, Colin Chapman, has said, "Adding power makes you faster on the straights. Subtracting weight makes you faster everywhere." Vins has taken this philosophy to its natural limits with the Duecinquanta motorcycle. Asotech played a key role in engineering this ultrahigh-performance motorcycle by using ANSYS topology optimization and fatigue life analysis to reduce the weight and ensure the durability of a key component.

References

New Atlas, Vins Carbon-Forked, Two-Stroke Duecinquanta Sportbike is the New Definition of Lightweight. newatlas.com/vins-duecinquanta-2-stroke-road-motorcycle/52773/ (12/29/2017)

Lotus, www.lotuscars.com/about-us/lotus-philosophy (03/28/2018)

Asotech, www.asotech.com/en/

Asotech Structural FEM Computation www.asotech.com/en/structural-fem-computation/

Shaping a STRONGER BRACKET

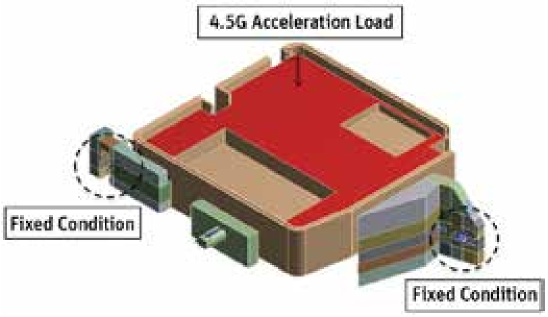
The intense heat and vibration in an engine compartment of an automobile can easily cause part failure. Kyungshin Corp. turned to topology optimization using ANSYS Mechanical to design stiffer, lighter brackets to support their smart junction blocks and reduce risk. Topology optimization cut development time in half while increasing the lifetime of the bracket and minimizing material costs.

By **Kim Byeongwoo**, Design Team Manager, Kyungshin, Incheon, Korea

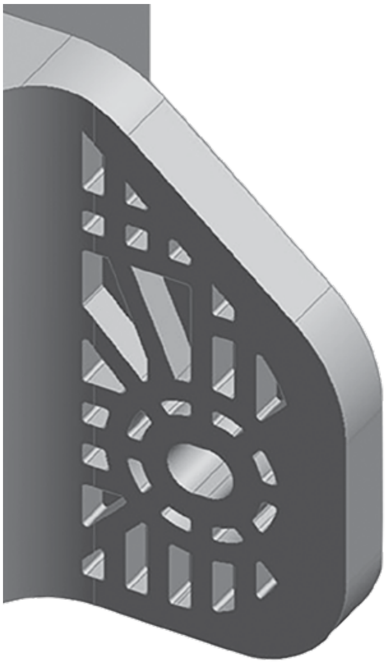
ORIGINAL MODEL

A smart junction block is the central nervous system of an automobile. The PCB of the junction box manages the electricity and distributes power to all parts of the vehicle, so it is a critical component of the modern car. Because of the vibration and high temperatures in the engine compartment, the junction block and the bracket that connects it to the chassis must be designed with high stiffness to resist cracking and vibration fatigue. Traditionally, the bracket was designed using a build-and-test method, which was slow and costly. Also, engineers tended to use more material than was necessary to ensure high stiffness, which raised the cost of raw materials.

To avoid such over-design problems and develop plastic junction block brackets with optimal dimensions to maintain the necessary stiffness, Kyungshin engineers used the topology optimization functionality of ANSYS Mechanical to design durable, lightweight brackets. With topology optimization, the simulation software automatically determines the best shape once engineers specify where supports and loads are located on a volume of material. For example, instead of a continuous solid bracket, topology



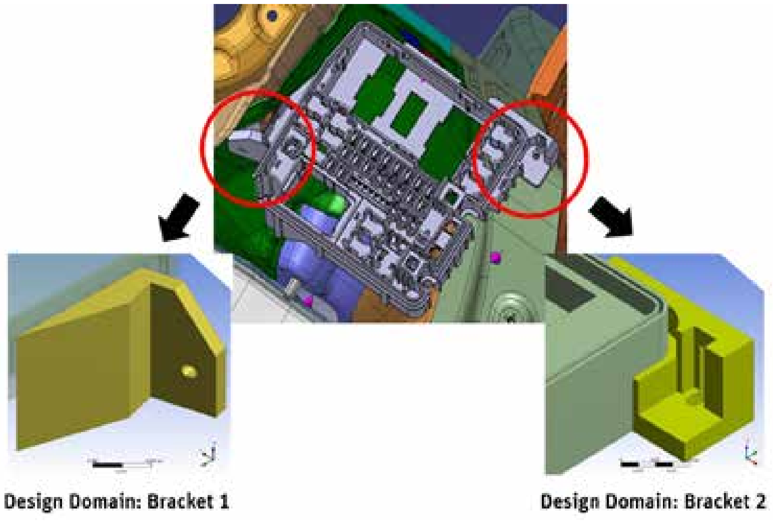
Definition of vibration simulation conditions



OPTIMAL MODEL

Optimal model of bracket based on optimal design value

"Using *simulation*, Kyungshin engineers reduced the development period for the *new bracket* from six months to three, greatly decreasing development costs."



Topology simulation optimization area

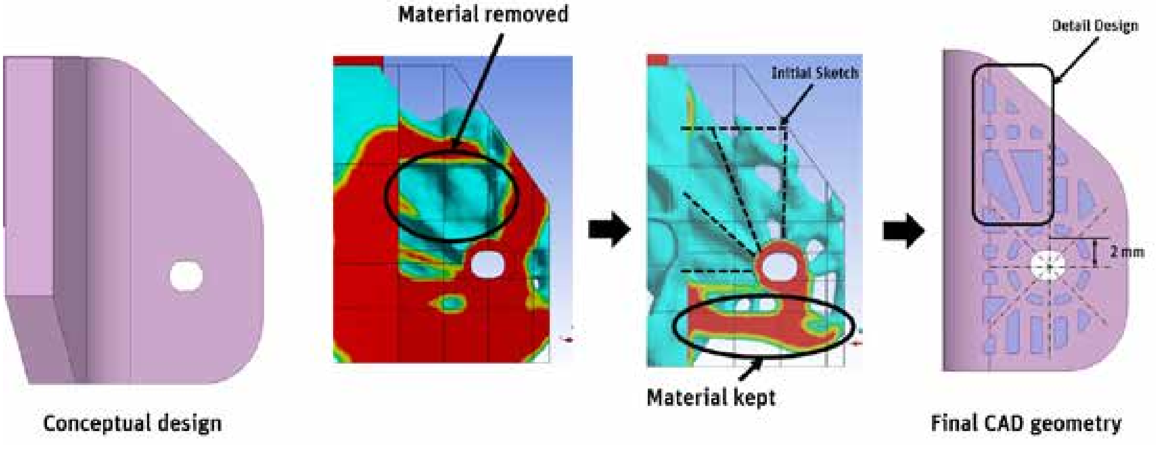
optimization might find that a lightweight design with ribs and void spaces produces a bracket that meets all mechanical requirements. In this case, ANSYS Mechanical's topology optimization capability performed digital exploration to determine the optimal bracket shape, rib shape and rib positions.

Three Steps to Success

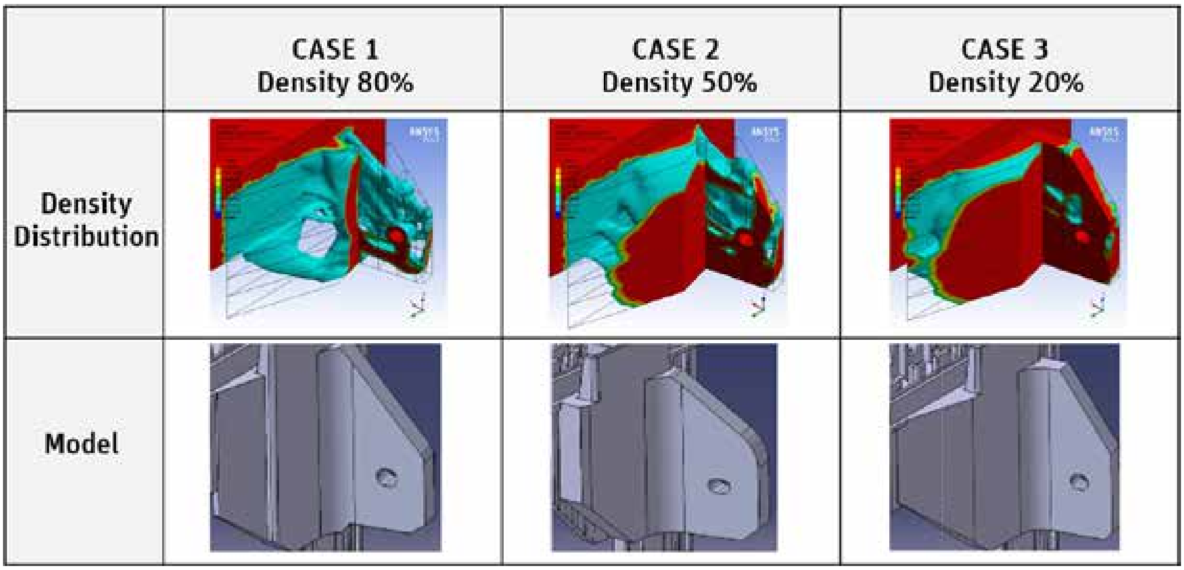
In the first step of the design process, Kyungshin engineers defined the load conditions experienced by the bracket in normal operation, established the allowable range of design parameters and generated an initial design based on the density distribution of the bracket using topology optimization. The bracket size was limited to the available space in the engine compartment that would not interfere with any nearby component. Engineers defined the vibration simulation conditions of the bracket by stipulating fixed points in the design and the acceleration load (4.5 G) experienced due to vibration. They then used topology optimization to generate an initial bracket layout using density distribution analysis. They explored brackets with density distributions of 20, 50 and 80 percent, and verified a bracket shape in each case that would provide the desired stiffness.

The second step involved shape optimization of the bracket based on the 50 percent density distribution model developed in the first step. Kyungshin engineers generated a parametric model with minimum and maximum dimensions for each defined design factor, including right and left side bracket width, height, angle and center radius. They then performed design of experiments (DoE) simulations automatically employing the manual central composite design (CCD) algorithm in ANSYS OptiSLang to obtain an optimal value for each parameter that resulted in a bracket with reduced mass and increased stiffness compared to the original bracket they were trying to replace.

Finally, the engineers verified the performance of the proposed optimal bracket using vibration fatigue simulation. The simulation

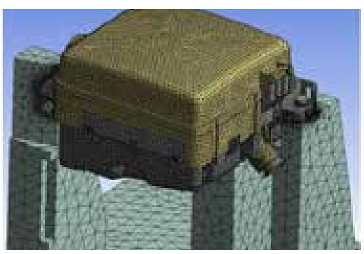


Initial layout shape of bracket rib



Result of density distribution for bracket 1

> **"*Topology optimization* ensures cost savings through designs that use the minimum amount of material necessary to meet required *mechanical standards* while increasing product lifetime."**



FEA model for vibration fatigue simulation

involved varying the vibration acceleration from 4.5 G to 3.0 G over three minutes while the vibration frequency varied from 20–50 Hz (at 4.5 G) to 50–200 Hz (at 3.0 G). The simulation also cycled the temperature from 90 C to –30 C back to 90 C over a 24-hour period to ensure that the bracket could withstand the temperature variations inside the engine compartment.

A Better Bracket

The vibration fatigue simulations revealed that the optimal model had a breakage lifetime of 2,259 operating hours versus 1,544 hours for the original bracket model. This is an increase in product lifetime of 46 percent — a significant improvement. The new bracket also was lighter, using 16 percent less plastic than the original, continuous solid bracket. In the process, Kyungshin engineers reduced the development period for the new bracket from six months to three months, greatly decreasing development costs. They also created a new thermal–vibration–fatigue simulation process using ANSYS Mechanical running on ANSYS Workbench to forecast the breakdown of the junction block bracket, which can be used in preventive maintenance scheduling.

By substituting simulation for traditional methods that relied on an engineer's experience and existing design standards, Kyungshin engineers have cut in half the number of bracket performance verification analyses, from eight to four. At a cost of approximately 50 million to 100 million won (US$45,000 to $90,000) per verification analysis, this is a major savings. In addition, they have produced a reusable model on which to base all future junction block bracket designs. The new model, employing ANSYS topology optimization, offers a flexible design scheme that the engineers can modify for any other component they may decide to manufacture in the future. Topology optimization ensures cost savings through designs that use the minimum amount of material necessary to meet required mechanical standards while increasing product lifetime.

ANSYS Topology Optimization
ansys.com/to

Personalized Implants Restore Smiles

By **Sarah Fink**,
Design Engineer and
Aaron Atkinson,
Design Engineer,
OMX Solutions,
Melbourne, Australia

When people are missing multiple teeth and large sections of their oral bone structure, they are not good candidates for standard dental implants. The usual treatment for this condition is bone grafting, which requires multiple staged surgeries that usually take a year or more to complete. With the help of ANSYS Mechanical, OMX Solutions uses additive manufacturing to produce implants that fit the jaw and match facial contours and require only a single surgery. Those affected can have their appearance properly restored and can eat immediately after surgery.

Dental procedures can be trying for many people. A filling, an implant or even a root canal are minor compared to the replacement of multiple teeth and large sections of bone that is required when trauma, fractures, tumors, degenerative bone disease and other issues occur. Severe bone loss is usually treated by harvesting bone from the patient's rib or fibula (in the leg), which requires at least three traumatic surgeries over 12 to 18 months. These same problems, as well as osteoarthritis and other conditions, may necessitate the replacement of the temporomandibular joint (TMJ), commonly known as the jaw joint. The jaw joint may be replaced with off-the-shelf components that often leave patients with a poor fit and reduced functionality. OMX Solutions, a world leader in digital solutions for surgical challenges, has developed improved solutions by using digital design and additive manufacturing to produce custom implants that fit the

CAD model of Osseo-Frame

Before

After

“Simulation identifies potential *problems* with the *interactions between components* and gives an indication of potential points of *failure*.”

patient’s existing bone perfectly. OMX Solutions uses ANSYS Mechanical to simulate the bone and implant as a unit, which, when confirmed with physical testing, ensures that these implants can withstand forces associated with mastication. The result is made-to-order facial and jaw implants that improve surgical outcomes, enhance quality of life, significantly reduce the number of surgeries required and eliminate donor site pain and morbidity.

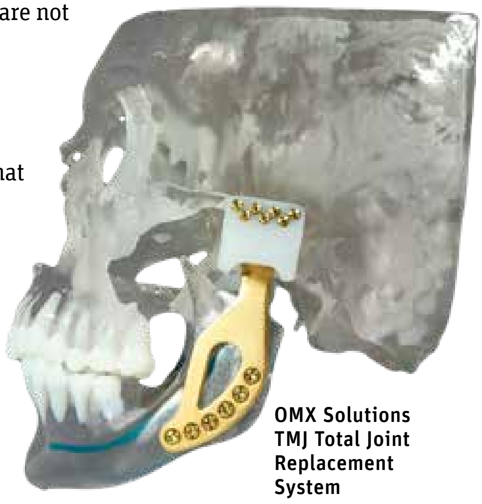
LIMITATIONS OF CONVENTIONAL IMPLANTS

When a large amount of bone and multiple teeth are missing, conventional dental implants do not provide enough stability to resist bite forces. Another option is a temporary removable denture, which can be uncomfortable and unstable. To remedy this, surgeons usually perform one procedure to remove a bone from the donor site and implant it into the jaw. Additional surgeries are required to implant teeth. The patient requires considerable time for recovery between surgeries, and the total time to complete the repair can be a year or more. Because the bone-grafting process is complex, it is difficult to match the patient’s facial contour, so patients are often left with an unbalanced look. Pain and donor site infection are also common.

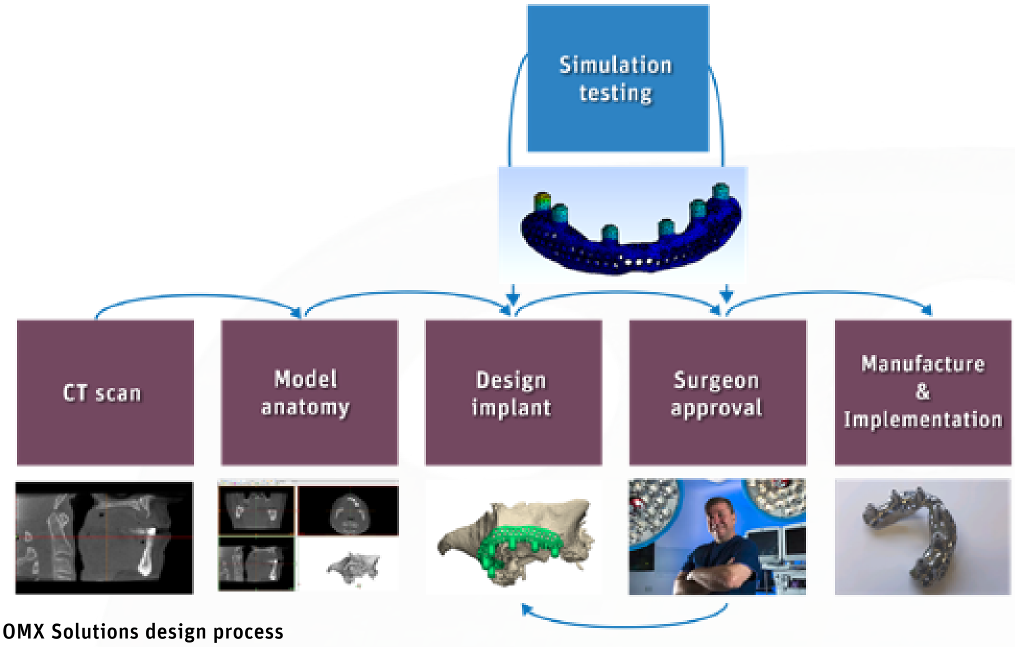
When TMJ replacement is required, the limited number of standard TMJ implant sizes available does not conform to the wide range of jaw and bone-loss configurations that are encountered in clinical practice. If there has been major bone loss, patients may be left with deformities and poor TMJ function because the stock implants are not fully compatible with the patient’s condition and morphology.

NEW APPROACH USES ADDITIVE MANUFACTURING

OMX Solutions has developed solutions to address these conditions. The OMX Solutions Osseo-Frame is a jaw implant that provides a secure, rigid bone replacement and mounting point for dental prostheses. It eliminates the need for bone grafts when the native bone site is not suitable for conventional dental implants. The implant is digitally designed and 3D printed to match the patient’s alveolar bone ridge, which ensures that the device perfectly fits to the natural bone without the need for bone modification. The microscrews and baseplate provide primary stability, so that the implant (and artificial teeth) can immediately be loaded without a protracted healing period.



OMX Solutions TMJ Total Joint Replacement System



OMX Solutions design process

The OMX Solutions TMJ Total Joint Replacement completely replaces the patient's temporomandibular joint. The 3D-printed titanium mandibular component is digitally sized and adjusted to fit each individual patient's bone structure using the patient's computed tomography (CT) data. The polyethylene fossa is also digitally sized and customized using computer numerical control (CNC) machining. The two then work together as a custom-fitted ball (condyle) and socket (fossa) joint.

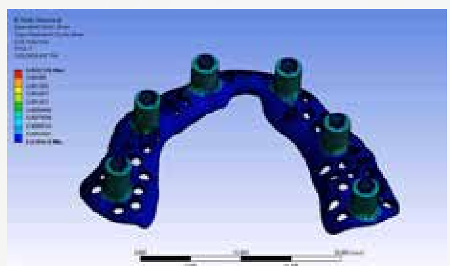
Both systems can be supplied with cutting, drilling and positioning guides to improve surgical precision.

DESIGN PROCESS FOR CUSTOM IMPLANTS

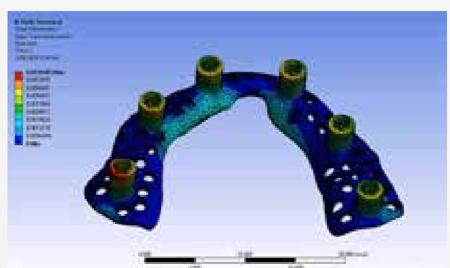
The first step in customizing these devices to the bone contours of the individual patient is to perform a CT scan that accurately shows the geometry of the patient's existing bone structure. OMX Solutions production engineers then use Materialise Mimics® software to convert the CT scan output to a digital model of the patient's bone and Materialise 3-matic® software to design the implant to closely match the patient's 3D skeletal anatomy.

In designing custom implants, OMX Solutions production engineers must ensure that the entire assembly, including bone, attachments and implant components, will not fail. Without simulation, it would be necessary to print each implant and conduct physical tests on them. If it did not pass, it would be necessary to redesign, remanufacture and retest, which is expensive in both time and money. Moreover, conducting physical tests on the entire implant–bone assembly for every patient is not possible.

Patient-specific simulation is the only way for OMX Solutions to cost-effectively ensure the integrity of each implant.



Display of equivalent strain experienced in an Osseo-Frame



Display of total deformation occurring in an Osseo-Frame

Personalized Healthcare
ansys.com/personalized-healthcare

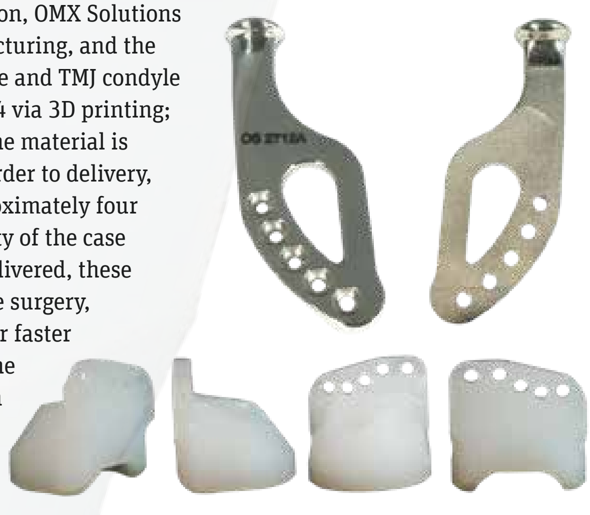
ANSYS MECHANICAL SIMULATION

OMX Solutions selected ANSYS because of its intuitive user interface. The company's production engineers first simulate the device alone using the average bite force as found in the literature. This is typically the average bite force of a 25-year-old male, although the average patient for OMX products is older and has reduced muscle strength. As such, they have a less powerful bite, so this approach provides a comfortable margin of safety. Once they are confident with the device integrity, the engineers then simulate a full mock-up, including a multimaterial model of the bone derived from the CT scan and the screws attaching the implant to the bone. All materials are treated as nonlinear. This model includes frictional contacts between the bone, screws and the implant. Contact detection is used to register the contacts that occur between each face of each screw in the bone model and to identify any potential separation that may occur during use, such as the frame coming off the bone. The run time of this simulation is typically two to five hours on a 4-core personal computer.

"OMX Solutions has developed improved implant solutions by using *digital design and additive manufacturing* to produce custom jaw implants that fit the patient's existing bone perfectly."

This simulation identifies potential problems with the interactions between components and gives an indication of potential points of failure. For example, it may show where the screw may cause bone fracture due to high levels of stress that are induced locally or where the screws are not capable of securely fastening the implant. When OMX Solutions production engineers are confident that the assembly is secure, they provide the design to the surgeon for review. The surgeon sometimes suggests changes based upon clinical feasibility and usability, in which case another round of simulation may be required.

Once they have approval from the surgeon, OMX Solutions transfers the digital design files to manufacturing, and the components are produced. The Osseo-Frame and TMJ condyle components are produced from titanium-64 via 3D printing; the fossa component is CNC machined as the material is currently not able to be 3D printed. From order to delivery, a custom implant can be produced in approximately four to eight weeks, depending on the complexity of the case and the experience of the surgeon. Once delivered, these devices are ready for installation in a single surgery, providing a permanent solution up to a year faster than traditional methods, at a fraction of the total surgical cost and significant reduction in pain and morbidity for the patient.



TMJ Total Joint Replacement Systems components include mandibular (top) and fossa (bottom).

Those with bone loss and reduced jaw function can find it difficult to enjoy food and eat a healthy diet. They may also have reduced self-esteem because of their appearance. OMX Solutions implants help these people rapidly recover their previous dental function and smile without undergoing a long series of operations. Patients who could not move their jaw in the past without pain can now eat and talk comfortably. People who had difficulty chewing and were not candidates for conventional implants can now eat normally. Patients whose faces had a sunken or lopsided look due to bone loss can be restored to their previous appearance. OMX Solutions custom implants restore a patient's ability to eat, speak and smile with renewed self-confidence and peace of mind.

Put a Cap on DDR System Power Supply Noise

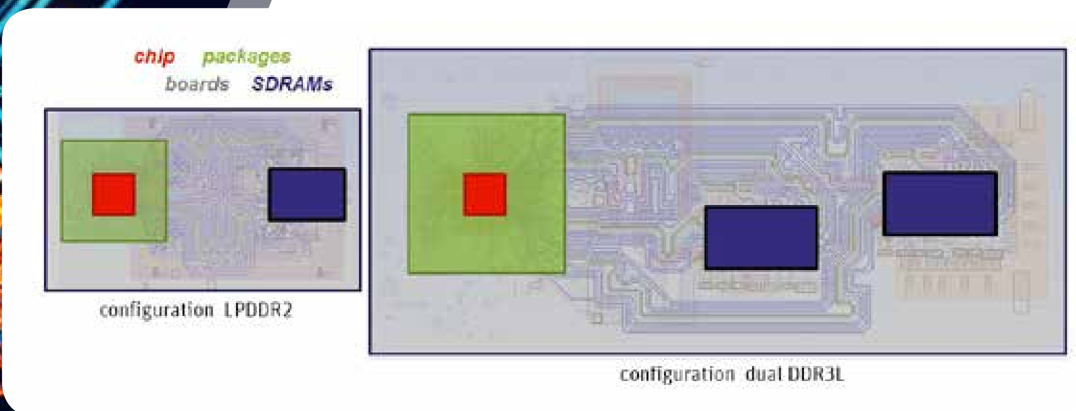
SMART, CONNECTED PRODUCTS require more functionality in smaller multivariant packages. As the global power budget is reduced and the operating frequencies required to deliver rich features increase, engineers are confronting the issue of power supply noise. The chips, packages and printed circuit board all contribute to power supply noise, so the complete system must be optimized to limit noise across the voltage and ground terminals of the transistors for error-free performance. STMicroelectronics engineers used ANSYS tools to identify and correct a power integrity problem in the complex design of a DDR system that might have otherwise delayed the product launch.

By **Déborah Cogoni**, **Laurent Schwarz** and **David Auchère**,
Signal & Power Integrity Engineers, STMicroelectronics,
Grenoble, France

In developing a reference board for a new DDR system, STMicroelectronics engineers needed to achieve signal and power integrity within a tight schedule. Optimizing this design required modeling everything, including the on-chip DDR physical device (PHY), the protocol to connect a PHY, memory chips, packages, printed circuit board (PCB), decoupling capacitors and so on. STMicroelectronics engineers used ANSYS Electronics Desktop and SIwave to simulate the complete system design in the frequency and time domains. They found and fixed a problem that, if not detected early, might have required another design spin. The integrated simulation methodology provided by the ANSYS signal and power integrity toolset reduced the time required to validate multiple configurations from two or three weeks in the past to just one week.

SIMULATING THE COMPLETE SYSTEM

The DDR system can be used with a single PHY for multiple memory configurations, including single or multiple DDR2 or DDR3 chips. Engineers needed to test signal and power integrity compliance with each possible memory configuration in the reference board design. Customers often design their own boards



In a new DDR system, a single physical interface chip (red) can be associated with different memory configurations (blue).

based on the reference board, and STMicroelectronics supports customers using spinoffs of the reference board design.

STMicroelectronics engineers began the simulation process by importing the electrical model of the integrated on-chip DDR (PHY model and patterns), package and board created by their designers, and various memory chip models provided by manufacturers into SIwave. Engineers then solved the imported structures and performed multiple simulations to compute resonances, trace characteristics, discontinuity reflections, intertrace coupling and the like. Engineers extracted S parameters, an IBIS interconnect model and a full-wave SPICE model. These were imported into ANSYS Nexxim, SIwave's circuit simulator, for time- and frequency-domain analysis.

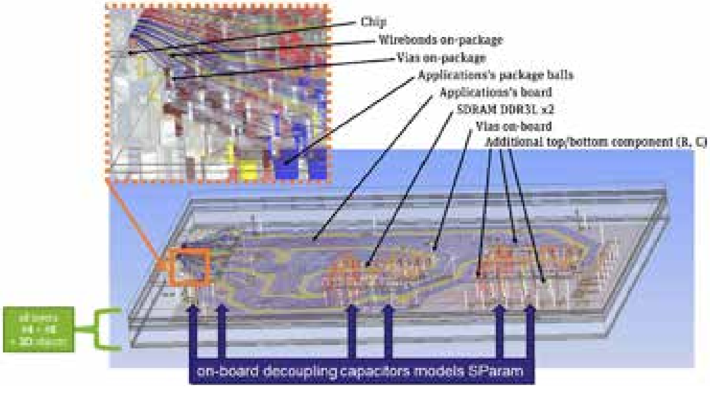
> **“This method has reduced DDR system validation time by 50 to 66 percent, and has become the standard workflow at STMicroelectronics.”**

The team used Nexxim to generate time-domain eye diagrams and to check the data timing and voltage for overshoot and jitter. The port excitations were set by drivers in IBIS format, using a pseudo random bit sequence (PRBS) to reproduce real use cases. Eye diagrams are used to indicate the allowable window for distinguishing bits from each other at the receiver end. The required height of the window is given by the noise margin of the receivers. The eye diagram initially showed differential skew between the byte lanes. Depending on the PRBS setting, DQ (data) signals overlapped one another.

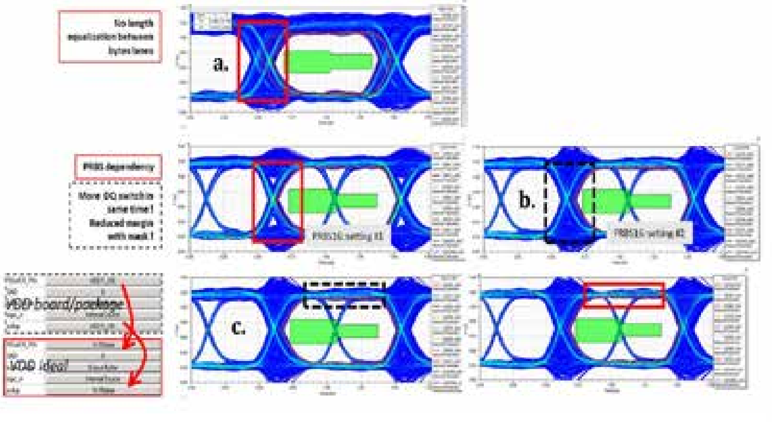
DIAGNOSING THE PROBLEM

To diagnose the problem, STMicroelectronics engineers used ANSYS SIwave to analyze the complete system power delivery network, including dies, packages, PCB and discrete coupling capacitors. The edge rate issues seen in the eye diagrams were traced to power plane noise. The charge needs to be supplied at a broad range of frequencies that depend on the edge rate. The decoupling capacitors must support this frequency range; for the reference board, they were originally specified based on the data sheets, which is a one-size-fits-all approach.

Engineers used SIwave to calculate power-plane impedance as a function of frequency with and without capacitors. The results showed that with no decoupling capacitors there is a high impedance peak of approximately 100 ohms. With the decoupling capacitors specified based on the data sheet, maximum impedance was reduced to 7 ohms, 1/14 of the original value, but still large enough to cause the problems seen in the original eye diagrams.



Complete system S-parameter model



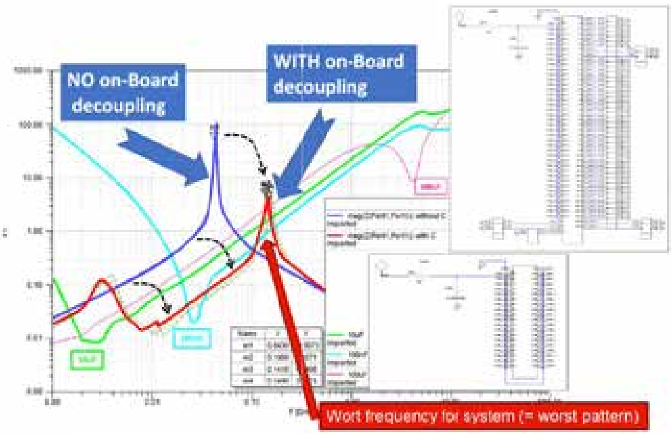
Eye diagram results for optimized design

ITERATING TO AN OPTIMIZED DESIGN

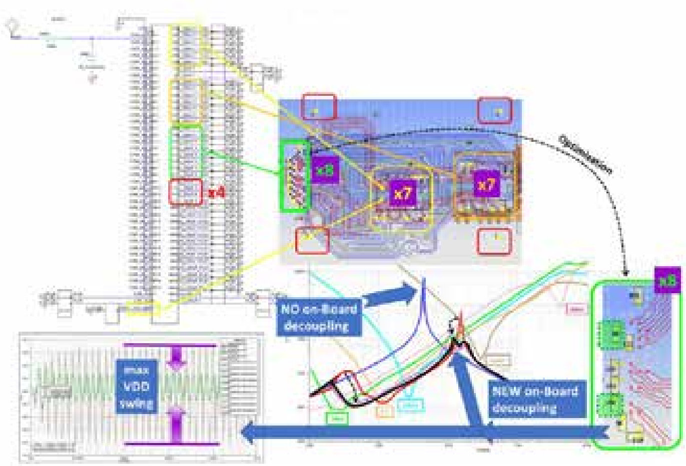
STMicroelectronics engineers then ran SIwave's automated decoupling capacitor analysis to properly dampen resonances within the power delivery network while taking decoupling capacitor parasitic inductance and mounting location into account. SIwave uses a genetic algorithm that enables users to constrain impedance peaks, as well as the number, type and cost of capacitors, as part of the cost function. The optimization algorithm iterated to a new design with specific decoupling capacitors that again allowed reducing the new impedance peak of power delivery network up to 1.1 ohms on high-bandwidth frequency.

The simulation showed that the drain supply voltage (VDD) swing was well within the specifications of the integrated circuits used in the reference board design. Finally, STMicroelectronics engineers imported the new design into Nexxim and re-ran the eye diagrams. The eye diagrams for the optimized design showed that the problems seen in the original eye diagrams had been corrected.

Based on a single global model that covered chips, packages, decoupling capacitors and the PCB, STMicroelectronics engineers were able to check signal and power integrity, and identify problems in both areas. They then made corrections and validated the optimized design. This method has reduced DDR system validation time by 50 to 66 percent and has become the standard workflow at STMicroelectronics.



Impedance as a function of frequency for initial design



Impedance as a function of worst frequency for optimized design

10x More Productivity for Chip-Package-System Workflows
ansys.com/cps-workflows

Taking the Metal Out of the PEDAL

Traditional optimization methods are limited in the weight savings that can be achieved; they change dimensions but not the overall shape of the part. Topology optimization, on the other hand, redesigns a part to minimize its weight while meeting loading and other requirements specified by design engineers. KSR International used this new approach to reduce the weight of an automotive brake pedal by 21 percent and decrease structural optimization time from 7 to 2 days.

By **Sachin Hardikar**, Computer Aided Engineering Engineer
Ryan Elliott, Engineering Manager
Shaun Fuller, Assistant Engineering Manager
Dave Morrison, Assistant Team Lead
Ben Hill, Engineering Specialist
Grant Gabriel, Designer
Daniel Leem, Technical Specialist
Derek Jackson, Program Manager
KSR International, Ridgetown, Canada

The automotive industry is continuing its efforts to reduce average vehicle fuel consumption and emissions. The most effective way to achieve both goals is to decrease vehicle weight. A 25 percent reduction in vehicle weight lessens fuel consumption by approximately 10 percent, while a 25 percent decrease in aerodynamic drag yields only about a 5 percent reduction in fuel consumption.

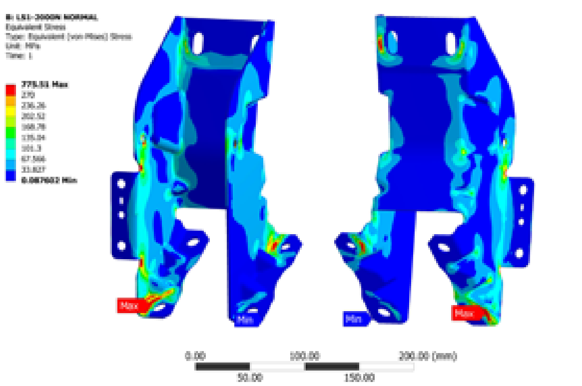
Early efforts at cutting weight focused on the largest and heaviest assemblies, such as changing from cast iron to aluminium engine blocks. With such large weight reductions already accomplished, automobile original equipment manufacturers (OEMs) and suppliers now focus on squeezing every last unnecessary ounce out of smaller parts. KSR International engineers used ANSYS topology optimization to largely automate the process of redesigning a brake pedal. Compared to conventional design methods, digital exploration using topology optimization reduced structural optimization time from 7 to 2 days while achieving a 21 percent weight savings, which is considerably more than could have been accomplished using conventional methods.

“With ***large weight reductions*** already ***accomplished***, automobile OEMs and suppliers now ***focus on squeezing*** every last unnecessary ounce out of ***smaller parts***.”

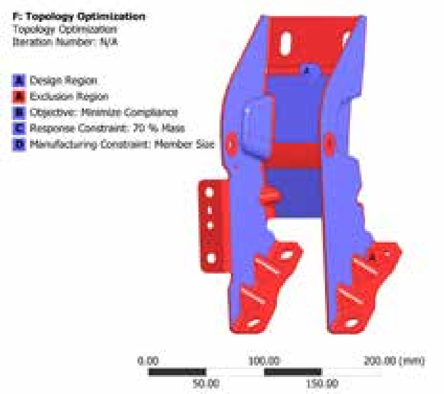
ROLE OF THE BRAKE PEDAL

KSR International is an industry leader in the design, engineering and manufacture of numerous automotive sensors, including accelerator pedal modules, electronic throttle control sensors, adjustable and fixed pedals, electric steering control units, and power modules for automobiles, light trucks and all-terrain vehicles (ATVs). The company makes more than 14 million fixed brake and clutch pedal modules a year. The brake pedal is the primary driver interaction point with the braking system and must transfer all normal and abnormal loading that can occur in panic situations while remaining fully functional.

The brake pedal optimized in this project is designed to withstand a pushing force exerted by the driver of more than 2,000 Newtons and significant lateral and reverse loads. Finite element analysis with ANSYS Mechanical showed low stresses in many areas of the pedal under all four load cases, which indicated the potential for weight removal. The traditional approach to reduce the weight of the pedal was to develop new designs for simulation, either one at a time by manually defining their geometry or dozens at a time by parametrically varying their dimensions. It would take an engineer using this approach about 1.5 weeks to achieve substantial weight savings by decreasing material in low stress areas, rerunning the simulation, then modifying the design based on the simulation results. For this application, conventional methods would have been likely to achieve significant weight savings, but the final design would not be fully optimized from a weight standpoint.



Stress analysis of original design with pushing load shows that stresses are low (blue areas) in most of the part.

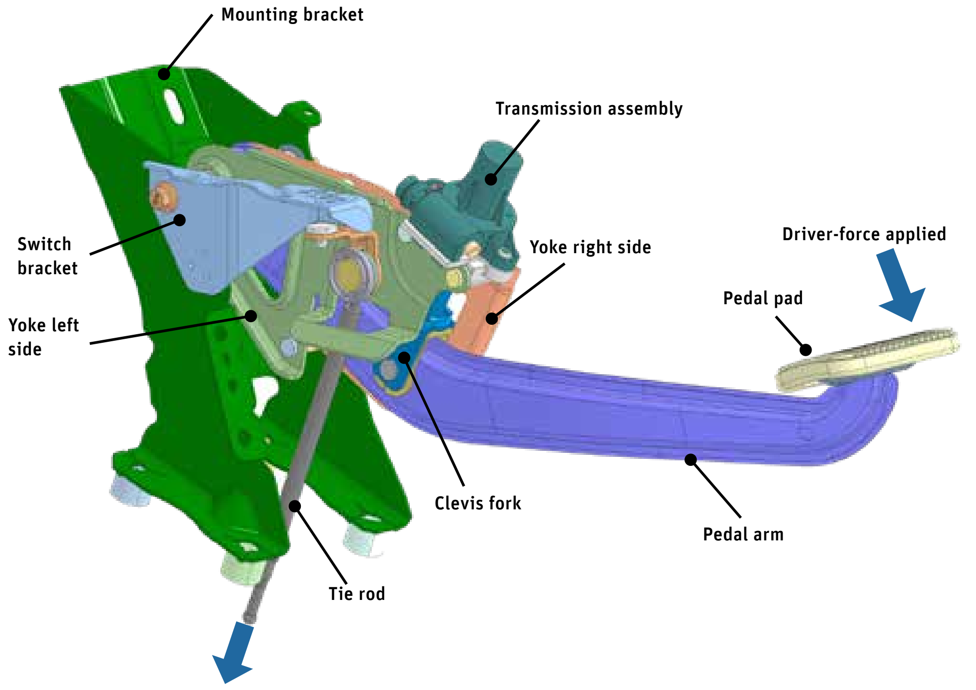


Areas marked in red must be maintained during topological optimization.

REDESIGNING THE PART

The ANSYS topology optimizer goes beyond incremental changes, such as adjusting the size or thickness of individual features, by essentially starting with a blank sheet of paper and designing the part from the beginning to meet objectives specified by the engineering team. The topology optimizer is integrated with ANSYS Mechanical within ANSYS Workbench. KSR engineers defined the features that must be maintained in the final design as the outer boundaries and mounting surfaces (where the pedal is attached to other parts) of the initial design. They set up the simulation so that the thickness throughout the part was the same as the previous design, which was required to meet

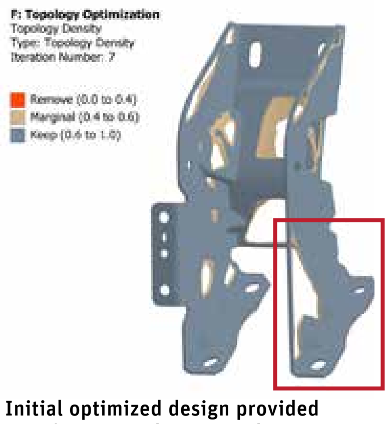
ANSYS in Action: Topology Optimization
ansys.com/to-video



When the driver presses the brake pedal, force transfers from pedal pad to tie rod and activates the brake boosters. The transmission assembly shown is part of an adjustable pedal system used on higher-end large vehicles so that the driver can adjust the brake pad positions (in combination with the accelerator pedal) within the vehicle to the driver's comfort level.

manufacturability constraints of the stamping operation used to produce the pedal. Engineers defined the optimization objective as minimizing the weight of the part while holding stress to a specified maximum value based on the material properties.

The ANSYS topology optimizer defined a geometry for all four load cases that met the design requirements at the lowest possible weight. KSR engineers performed another structural analysis of the new design. They determined that stresses were at acceptable levels throughout the part. They also observed that stresses were very low along one edge of the part, indicating the potential for additional weight savings. Because these low stresses were caused by maintaining the entire outer boundary in the final part, they achieved additional weight savings by removing this boundary.



Initial optimized design provided significant weight savings by removing materials where they were not required. Further weight savings were achieved by removing thin boundary highlighted in red.

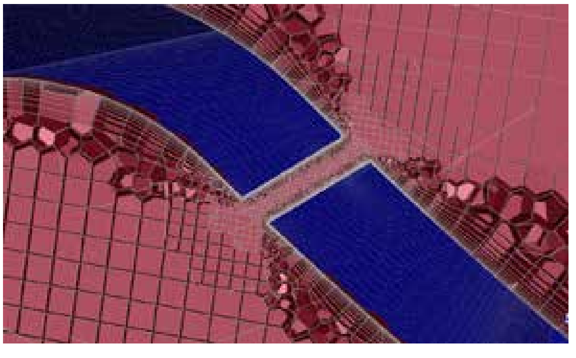
SAVING WEIGHT AND ENGINEERING TIME

The optimized design weighs 694 grams, a reduction of 192 grams from the 886-gram original design. The new design can be implemented at no additional cost because a new stamping die must be built whenever a pedal is designed for a new model vehicle. These improvements were achieved in only one and half days, far less than would have been required to optimize the design using traditional methods. It should be noted that this figure refers to the time required to meet structural requirements for a specific configuration of a pedal. Additional time is required to package a pedal for a specific vehicle configuration. The weight savings that were achieved by using topology optimization were much greater than what could be achieved by changing design parameters with either manual or automated optimization. The automotive OEM that buys the brake pedals from KSR is very pleased with the weight savings. KSR plans to use topology optimization in the future to achieve substantial weight savings without having to invest significant engineering resources.

Simulation in the **News**

ANSYS 19.2 Delivers Faster Problem-Solving
Capabilities Across the Entire Portfolio

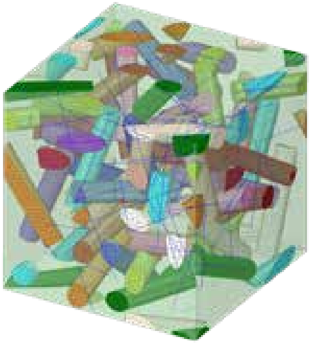
From innovative fluids meshing technology to improved workflows for safety analysis to an updated system coupling engine, the newly released ANSYS 19.2 enables customers to solve their most difficult product development challenges faster than ever. This latest release empowers more users to accelerate the design process with new single-window, efficient workflows and patent-pending advanced meshing technology for computational fluid dynamics (CFD). ANSYS 19.2 also includes new processes for developing embedded software for safety-critical applications, and dramatic computational speed and user experience improvements for solving automotive radar scenarios, digital twins, 3D design exploration and structural modeling.



“ANSYS Fluent meshing in 19.2 has been extremely beneficial to us in terms of turnaround times compared to the previous versions, especially in handling large, complex geometries. The resulting mesh also meets and exceeds our quality requirements in every aspect. All of these put together have greatly improved our productivity, while reducing manual efforts required.”

— **Vidyanand Kesti,** CFD specialist, Mann and Hummel

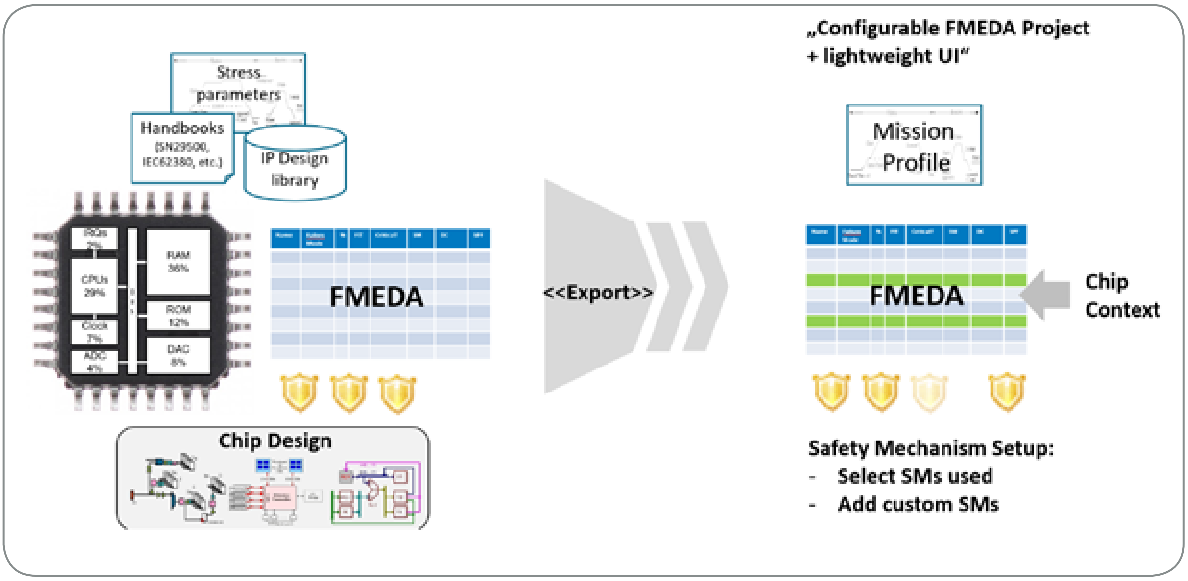
ANSYS VRXPERIENCE takes predictive validation of vehicle systems to the next level — meeting any virtual reality simulation and validation need for autonomous vehicle simulation.



The new material designer feature for structural simulations can create detailed models of sample materials and then calculate equivalent properties for use in larger-scale simulations.

ANSYS 19.2
ansys.com/19

ANSYS 19.2 Delivers Faster Problem-Solving Capabilities Across the Entire Portfolio



"Through the use of task lists and libraries, medini analyze has helped Allegro improve the quality and standardization of safety analysis across business units, while at the same time increasing efficiency through re-use."

— **Paul Amons,** functional safety manager, Allegro MicroSystems

AERODYNAMIC SIMULATION REVEALS BEST POSITION IN A PELOTON OF CYCLISTS

HPC Wire, July 2018

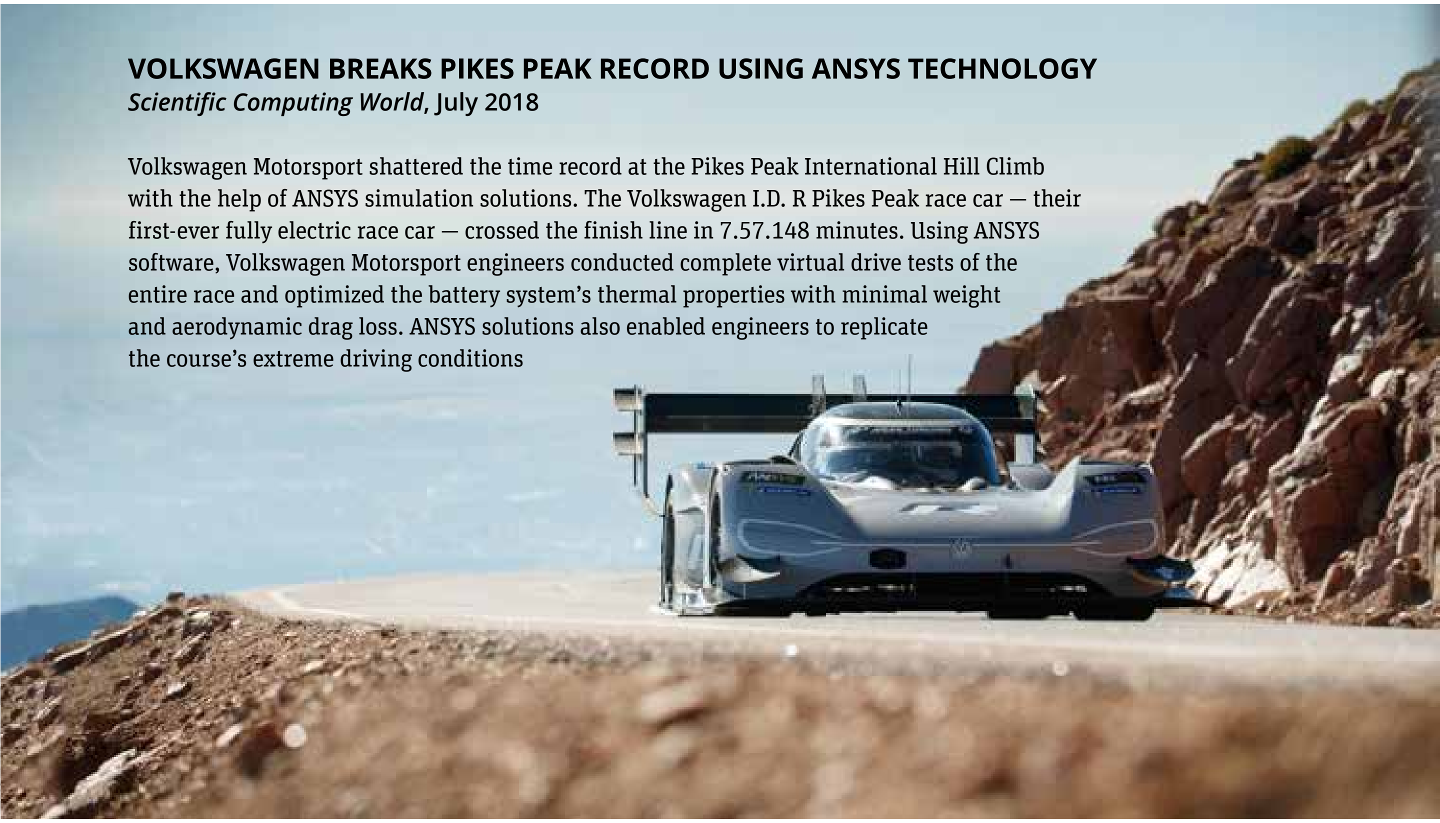
The position of a cyclist in a race could affect its outcome. But what is the best position? Researchers at Eindhoven University of Technology and KU Leuven, led by Professor Bert Blocken, ran a 3-billion-cell ANSYS Fluent simulation on a Cray computer to find out. By determining the flow pattern between each cyclist in the peloton, the team found that the riders at the core of the peloton experience much less drag than was previously expected. This was the largest CFD model ever performed for sports.

First Computer Simulations and Wind Tunnel Tests of Full Cycling Pelotons Give Breakthrough Insights
ansys.com/pelotons

ANSYS, SAP SPIN DIGITAL THREAD BETWEEN ENGINEERING AND INDUSTRIAL OPERATIONS

Digital Engineering, July 2018

ANSYS is pairing its digital twin technology with SAP's cloud platform and manufacturing and asset management software portfolio to create a platform to help manufacturers optimize operations and maintenance based on real-time engineering insights.



VOLKSWAGEN BREAKS PIKES PEAK RECORD USING ANSYS TECHNOLOGY

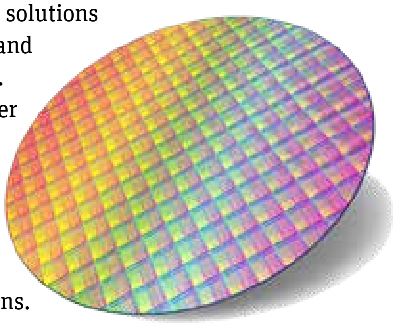
Scientific Computing World, July 2018

Volkswagen Motorsport shattered the time record at the Pikes Peak International Hill Climb with the help of ANSYS simulation solutions. The Volkswagen I.D. R Pikes Peak race car — their first-ever fully electric race car — crossed the finish line in 7.57.148 minutes. Using ANSYS software, Volkswagen Motorsport engineers conducted complete virtual drive tests of the entire race and optimized the battery system's thermal properties with minimal weight and aerodynamic drag loss. ANSYS solutions also enabled engineers to replicate the course's extreme driving conditions

GLOBAL SEMICONDUCTOR LEADER HISILICON LEVERAGES ANSYS TO DRIVE PRODUCT INNOVATION

TIE Silicon Valley, July 2018

Global semiconductor leader HiSilicon Technologies Co. is innovating the next generation of mobile, networking, artificial intelligence and 5G products by applying ANSYS solutions to power integrity and reliability analysis. ANSYS' 7-nanometer customers deploy ANSYS RedHawk-SC for signoff of their most complex products and designs.



SAMSUNG FOUNDRY CERTIFIES ANSYS FOR SELF-HEAT, POWER INTEGRITY AND ELECTROMIGRATION SOLUTIONS

ANSYS.com, June 2018

Customers of Samsung Foundry and ANSYS will create the next generation of robust and reliable electronic devices thanks to Samsung Foundry's certification and adoption of ANSYS solutions for power integrity and reliability analysis. This certification enables extraction, static and dynamic voltage drop analysis, self-heat and electromigration analysis for both power and signal nets for Samsung Foundry's latest 7-nanometer Low Power Plus (7LPP) lithography process technology.

SPARC RESEARCH, ANSYS AND F1 COMPUTER SOLUTIONS JOIN FORCES TO MODERNIZE MISSILE PROPULSION DESIGN

MarketsInsider, August 2018

SPARC Research has partnered with ANSYS to leverage modern multiphysics analysis tools in the design and optimization of rocket and ramjet engines. The company, a member of the ANSYS Startup Program, hopes to reduce the time from requirement generation to prototype demonstration through simulation.

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

Send address corrections to
AdvantageAddressChange@ansys.com