

DEGREES OF FREEDOM

By Brian Albright



Sailing Into Advanced Design

HE AMERICA'S CUP RACE has evolved into a competition that is as much about design and engineering as it is about sailing acumen. As Senior Editor Kenneth Wong outlines in two indepth features, the teams involved increasingly rely on digital simulation to design the yachts for the race. This was particularly true heading into the 2021 event, as teams were piloting an entirely new type of monohull boat, but also because the COVID-19 pandemic forced everyone involved to find new ways to collaborate.

The challenges posed by the pandemic continued to affect the race right up to the very last moment. As I write this, Auckland was placed under a Level 3 lockdown for 72 hours that forced a delay of the February Prada Cup events leading up to the March competition.

The America's Cup Match scheduled for March 6-21 was already being held under unusual restrictions. Practices and even transportation of the boats to New Zealand became more complicated during the pandemic, and there are restrictions related to spectators.

Still, even those complications highlighted just how important technology has become to the race as teams leveraged remote technology and cloudbased solutions to finalize designs, make adjustments to their vessels, and remain in contact with one another.

Simulation played a key role in each team's design, and the engineering advancements made possible by these tools have helped accelerate top race speeds by nearly five times over the past decade. The boats in this year's race will fly over the water at an unprecedented clip.

Elsewhere in this issue, our writers take a look at other new tools in the engineering toolbox. We have included a feature looking at new lowcode development tools that are changing the way designers interact with their software. We have also included a feature comparing how engineering software is taking advantage of rapid advancements in CPU and GPU computing. We also take a look at the convergence of

generative design and additive manufacturing, relative to lightweighting efforts across multiple industries.

That vendors and their customers in the engineering space have continued to innovate during what is soon to be a full year of pandemic-related disruption speaks to the resiliency of this industry. In numerous conversaThe engineering advancements made possible by these tools have helped accelerate top race speeds by nearly five times over the past decade.

tions I have had over the past several months, the idea of resiliency has come up again and again as a key lesson we can take away from 2020.

In the past 12 months, we have seen every aspect of our lives rearranged. Everything from getting groceries, to sending our kids back to school, to collaborating with our peers has been affected.

Even though the America's Cup will look a little different this year, design innovation has contributed to the resiliency of the teams and the race itself.

Brian Albright, Editorial Director E-mail me at balbright@digitaleng.news

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TECHNOLOGY FOR OPTIMAL ENGINEERING DESIGN

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Focus on America's Cup

CFD Keeps Boats Afloat in the **America's Cup**

Despite COVID disruptions, sailing teams discover new ways to simulate the unexpected.

By Kenneth Wong



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Advanced CFD at the Helm in Competitive Sailing

New rules in America's Cup encourage virtual testing.

By Kenneth Wong



| DIGITAL THREAD

Low Code Aims to Democratize Thread Development

The technology shows promise in overcoming many hurdles tied to realizing the full potential of the digital thread.

By Tom Kevan

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Generative Design: A Heavyweight for Lightweighting with Additive

> The combination of generative design software and AM technologies is proving to be a go-to force for lightweighting and parts consolidation strategies.

By Beth Stackpole



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GPUs Invade Product Development



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Powering Up

Eaton embraces
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BY THE NUMBERS

Designed to Fly

100,000 HOURS

The amount of design time the American Magic team reported spending to create their AC75 Defiant for the America's Cup race.

The top speeds of the AC75 monohulls in the America's Cup race KNOTS have increased to the point that the race requires off-water umpires to monitor team progress via a remote video feed. In 2013, the average top speeds were around 40 knots: in 2010, the average top speed was just 10 knots.



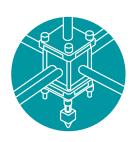
Image courtesy of America's Cup



Augmented Reality on the Rise

Executives who view AR as a key part of their digital transfer. of their digital transformation strategy. according to a study from Librestream.

AM Gains Traction



A new survey from Essentium found that **investments in** 3D printing are paying. According to the survey:

46% reported high part performance

46% reported cost reductions

45% reported speed-to-part improvements

Manufacturing executives also reported several obstacles to investment, including:

37% reported that **high costs** of 3D printing materials were a challenge

24% said 3D printing materials are unreliable



More **Materials**



COMPOUND ANNUAL

of the global 3D printing materials market, according to Technavio.

GROWTH RATE



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ARTIFICIAL INTELLIGENCE

Altair, Rolls Royce Bridge the Gap Between **Engineering and Data Science**

Partnership will address a wide variety of use cases, including applying AI to engineering test data and simulation.

BY BETH STACKPOLE

here's copious talk about how to leverage artificial intelligence (AI) and data analytics to achieve corporate goals like increasing revenues, cutting costs, or even mitigating risk. Now a pair of industry leaders—one hailing from the manufacturing world and the other from the simulation and engineering analytics software segmentare coming together to bridge the gap between engineering and data science.

Altair, a provider of simulation and analytics tools, and Rolls-Royce Germany, known for the design and engineering of aerospace engineers, have announced a collaboration to democratize Rolls-Royce's treasure trove of data analytics resulting from its engine health monitoring services, making it accessible to engineers to drive better design decisions.

The companies will work together to productionize high-value use cases using Altair's data and AI software, based on Altair Knowledge Works, including in the area of structural analysis and testing. The goal is to bring together vast amounts of historical product and in-service data from disparate sources such as in-field engines to unlock new AI-driven engineering use cases. The partners see opportunities in these areas:

Reducing and accelerating certification and design iterations by leveraging machine learning to predict where simulation is needed. In that way, teams can reduce the amount of



Altair and Rolls-Royce will work to productionize highvalue use cases using Altair's data and Al software. Image courtesy of Altair.

re-certification (simulations) needed.

Parring back on extensive physical testing by using ML to predict where and how you need to test. Early proof-of-concepts have shown this is possible, creating a direct correlation to development costs and lead time, according to Sam Mahalingam, Altair's chief technical officer. "This is one of the most high potential use cases we are working on with Rolls-Royce Germany," he says.

Cutting back warranty costs and improving product quality. Putting the power of data analytics into the hands of engineers will drastically improve product quality, he says.

By converging data science and engineering with new applications, the partners aim to cut back on the manual engineering work and domain expertise required to define what needs to be tested or which sensors to install and where. "Today this is done from experience and researching previously conducted tests," Mahalingam explains. "To do this effectively and efficiently is a challenge."

In the case of aerospace engines,

the complexity is even higher as there are often thousands of sensors with millions of historical data points. By mining engineering and testing data, machine learning can predict where testing is needed along with the location and number of sensors required for installation. "This can significantly reduce the number of sensors needed for a given test, which has a direct correlation to development costs and lead time," Mahalingam says.

Altair's Knowledge Works, a collaborative end-to-end analytics platform, will serve as the foundation of the collaboration. The platform's low code/ no code approach ensures engineering users can easily and efficiently access disparate data sources, transform data, and use it to build ML models. Mahalingam says Altair's domain expertise and best-in-class low-code data analytics technology was what drew Rolls-Royce Germany to the partnership.

Check out this video to learn more about Rolls-Royce's vision for the intelligent, truly connected engine of the future. DE

CES 2021

Cool Tech for the New Normal at CES 2021 Virtual

Touchless devices, touch minimizing Uls, and fashionable face shields are just a few

BY KENNETH WONG

ormally in January, people flew into Las Vegas, NV, for the annual CES (Consumer Electronics Show). However, this year, with traveling restrictions from the pandemic, the show was completely virtual.

The show's keynote speakers include Intel's Executive VP Gregory Bryant, AMD CEO Dr. Lisa Su, Microsoft President Brad Smith, and other big names in the telecom, entertainment, retail, and high-tech sectors.

Check out our video report at http:// youtu.be/wjaRJnPJIJM.

AMD Keynote at CES 2021

"For all of us the tech industry, although we have had our challenges, 2020 was perhaps our most productive year. From how we work to how our kids learn to our entertainment, we're accelerating the pace of digital transformation," said AMD's Dr. Su in her keynote.

The pandemic seems to have created a new demand for PCs for working from home. "In 2020, approximately 300 million desktops, laptops, and chromebooks were sold. That's the highest number since 2014," Dr. Su pointed out.

In the rest of her talk, Dr. Su announced the AMD Ryzen 5000 Series mobile processors with partners HP, Lenovo, and Microsoft.

Touchless and Touch-Minimal UIs on the Rise

During the pandemic, autonomous vehicles and smart devices continue to make new advances. What's noticeable are the various ways UIs have evolved to accommodate touch-less or touchminimized interactions using gestures and computer vision.

AI-driven IOT devices that can remember user's preferences and histories are also a highlight of the show, with



Wireless Bluetooth temperature checker Gatedoc is one of the products featured at CES 2021. Image courtesy of Gatedoc.

healthcare products and toys that keep track of the users' comfort level and react to gestures.

Fashionable COVID-Wear

The new normal has also opened up new markets for face shields that are not just functional but fashionable, optimized for audio communication while protecting you from virus exposure. (Check out the airsafe helmet here: segurollc.com/airsafe/.)

Computer-vision technologies are also playing a role in identifying and detecting risky behaviors and safety

violations. (Check out Gatedoc, the wireless Bluetooth body temperature scanner.)

For routine security and maintenance tasks, drones are set to play a larger role.

No Going Back

News and products at CES anticipate the new normal will not swiftly revert back to the old normal just because vaccines are on the horizon. Ouite the opposite, the behaviors, from sanitation to gesture-driven UIs, will likely endure because they make sense in general for safety. Tech leaders at CES are betting on it. DE



Functional and fashionable? The airsafe helmet featured at CES 2021 fits into this category. Image courtesy of airsafe.

3D Printed Parts Take Off on Boom Supersonic Flight

VELO3D Sapphire 3D printer is the engine for producing challenging titanium parts for XB-1.

BY BETH STACKPOLE

s part of Boom Supersonic's flight plan for a return to supersonic air travel, it took a turn towards metal 3D printing as part of a parts consolidation strategy and to output some of the XB-1 aircraft's most complex component designs.

Taking the lead from other aircraft manufacturers already equipping key aircraft with 3D printed components, Boom Supersonic decided to explore how metal AM technology from VE-

LO3D could deliver greater design flexibility, particularly around parts consolidation. A parts consolidation strategy would be essential for streamlining production and to improve safety and efficiency, officials said.

Instead of welding or bolting together multiple parts or using carbon-fiber tools, the company's parts consolidation approach leaned heavily on a designfor-AM strategy aimed at reducing weight by eliminating unnecessary joints and interfaces between components. "The goal of part consolidation is the elimination of parts through amalgamation," explains Gene Miller, application engineer at VELO3D. "In utilizing additive manufacturing, several parts can often be manufactured as one without the need for fastening material (flanges, weld plates,

nuts, and bolts, etc.). This is harmonious with lightweighting-of-design strategy because it reduces weight through the elimination of heavy fasteners and fastening material."

Much of the AM effort centered around parts designed to channel air through structures such as complex vanes, ducts, and louvres, all of which have to withstand extremely high heating temperatures, often in excess of 500 degrees Fahrenheit. Given their geometric complexity, the parts required a surface-based design approach, starting with aerodynamic profiles whose surfaces were then trimmed, filleted, and thickened to create a solid part. "The unique types of geometries created for directing flow, with a focus on weight savings, couldn't be done with sheet metal or casting or any other way," Miller



Boom Supersonic uses 3D printed parts. Image courtesy of VELO3D.

explains. "To reap the benefits of complex design and weight reduction together, the only option was to do it with metal AM."

Boom, together with its 3D printing partner Duncan Machine Products (DMP), settled on VELO3D's Sapphire laser powder-bed fusion (LPBF) technology to produce titanium components. Among the parts designed and printed with the Sapphire technology were manifolds for the Variable Bypass Valve (VBV) system used to route air released by the engine compressor to the aircraft's outer mold line (OML): exit louvers for the environmental control system that cools the cockpit and systems bay; louvers for directing the center inlet's secondary bleed flow to the OML; and NACA ducts and two diverter flange parts.

The team was able to print parts

directly from Boom's CAD data, preserving the original design intent and streamlining the overall process. "Using VELO3D's Sapphire technology, these optimized parts were manufactured according to the original design intent without the need for redesign or compromise," Miller explains.

The choice of lightweight, heat resistant titanium did make for some challenges when it came to AM parts production. Titanium can be delicate and difficult to work with, particularly prone to cracking if it is cooled too rapidly. However, the alternative means of production casting-would not have been able to accommodate the XB-1 thin-wall parts designs.

"To ameliorate cracking, VELO3D incorpo-

rates an in-situ stress-reduction technique that mitigates internal stresses accumulated during the printing process," he adds. "Working through these challenges required parameter optimization, which bolstered the robustness of our stress reduction especially for thin-wall components."

VELO3D Sapphire's post processing functionality was also another key advantage. The system required little work to slice parts off the build plate and once they were separated, there was little in the way of post-machining work required. Support removal was also a non-issue. "You don't have any tiny supports in small crevices or hardto-reach places because the Support-Free technology eliminates the need for those," Miller says.

To learn more about the effort, watch this video. DE

CFD Keeps Boats Afloat in the America's Cup

Despite COVID disruptions, sailing teams discover new ways to simulate the unexpected.

BY KENNETH WONG

n July 2019, when America's Cup announced the 2020 race dates, the biggest news headlines were the protests in Hong Kong and Moscow, and North Korea flexing its nuclear muscles with test missile launches. At the time, COVID-19 had not yet appeared.

Participating teams imagined their boats would be in the sun-soaked Mediterranean waters of Cagliari, Sardinia, with no delay. Then, in March 2020, came the unimaginable hurdle—the first wave of the pandemic.

The New Zealand team's full-scale boat Te Aihe was en route to the race venue on a container ship when travel and transportation disruptions occurred. The team was left without their physical boat for months, and lost precious time for physical testing, practice runs and data analysis. This was just one example of the challenges for the participants in the 36th America's Cup, which is set for March 6, 2021, in Auckland, New Zealand.

"All of the early test races in the America's Cup were cancelled in 2020 so the teams had much less opportunity to see how their designs compared to the other teams. This means the boat designs that will race in 2021 are more of a direct result of a simulation-based design process, and have not gone through the filter of 1+ years of real racing to refine the designs," says Riley

Schutt, U.S. Sailing Team's IR&D performance analyst, and fluid modeling and design specialist.

Also notable is the AC75 Class Rule, which was published in March 2018. It sets "strict limitations on the number of components that can be built, including hulls, masts, rudders, foils, and sails, thus encouraging teams to do more R&D in simulation and subsequently less physical construction and testing."

As a cost-control measure, the rules also put a "prohibi-

tion of tank testing, wind-tunnel testing and similar fluid dynamic testing."

All these factors suggest that for the 36th America's Cup, most of the competing teams' preliminary races took place not in the open water but in pixels and meshes inside high-performance computing (HPC) clusters, away from the public's eyes.



Remote Before COVID

Long before COVID and social distancing, remote working became the norm among the design teams involved in the America's Cup. That's because the teams usually involve globally dispersed talents, even if they represent specific countries.

"All the design team members are constantly involved in projects from different parts of the world. It's quite common to have to deal with constraints such as different time zones, as some team members and



The Luna Rossa Prada Pirelli engineering team used Altair OptiStruct to optimize the composite structures of the boat. Image courtesy of Altair.

many suppliers are based in different locations worldwide," says Alessandro Franceschetti, head of structural engineering for the Luna Rossa Prada Pirelli team from Italy.

The Italian's team official technology suppliers include simulation software maker Altair.

"With the capabilities of Altair OptiStruct, we maximize the use of sub-structuring and sub-modeling among others to be able to make progress in parallel with different design components without neglecting the influence of the rest of the general structural assembly of the yacht," says Franceschetti. "The extensive usage of the super elements allowed the structural department to efficiently exchange models and meet the deadlines with high-fidelity simulation results."

Schutt is preparing his team for the Tokyo Olympics and is not competing in this year's Cup; the U.S. is represented by The New York Yacht Club American Magic. However, he has ample experience with remote working in a collaborative design development.

"It is magnified this year because we cannot travel and be with each other in person. We are spread all over the world, so we rely a lot on cloud-based infrastructure that

allows us to share design," he says.

Schutt is a resident of the Outsight Network, which is a community of resident teams with the Autodesk Technology Centers. Before COVID, the Technology Centers' physical spaces in San Francisco, Boston and Toronto, served as places where program participants could come to learn and use manufacturing equipment (such as professional-grade 3D printers and CNC machines) to test and prototype their design concepts.

But in response to COVID, the program evolved with expanded virtual programming, networking and collaboration opportunities, while it also maintained its access to subject matter experts.

"Prior to COVID, we were primarily focused on North America-based teams, but taking our work remote has allowed us to support teams from across the globe. Having innovative teams from Asia, Europe, Africa and South America join the Outsight Network has enhanced the knowledge and expertise available to the other residents. This has enabled us to significantly expand the Outsight Network, adding 63 new resident teams since COVID began and creating a community of over 650 individual residents," he says.

Digital Twin Unaffected by Restrictions

INEOS TEAM UK, another contender in the 36th America's Cup, is supported by Siemens Digital Industries Software.

"As a team we were well-placed for people working remotely but the cancellation of the planned events in Cagliari and Portsmouth affected us, as it did all the teams, in that we lost racing time against our competitors, which meant we did not have a good benchmark for where we were at compared to them," says Max Starr, INEOS TEAM UK CFD Engineer. "COVID of course also severely reduced the time we had on the water with our first boat, which would have helped with our testing program overall."

To make up for lost time, INEOS TEAM UK began to rely more on simulation.

"A lot of people who would have been involved in the physical testing were building more complicated

computational models in-house and a lot of that then fed into CFD (computational fluid dynamics) ... It just meant that we were busier in the digital world," says Starr.

Starr and his team are using Siemens' NX software for the boat's design, and product lifecycle management (PLM) portfolio Teamcenter to keep everyone in sync with the design iterations. They also use Siemens' Simcenter STAR-CCM+ software for CFD.

"After the Christmas Cup, we went back to look at a lot of our old simulations setups and we ran a lot of 'what-if' scenarios to try and understand where the performance deficit came from," says Starr.

"It was a case of trying to run a lot of simulations to help validate what we were seeing in real life ... Because we had the digital twin of the boat, we could run many 'what-if' scenarios to try and understand what we were seeing on the water versus what we were seeing in the models to try and correlate between the two," he adds.

Reading the Wind and the Water

The race site is usually an unpredictable factor, perhaps more so in the 2021 race. With limited travel options in the last year, it's safe to assume few teams except the New Zealand team, which is located on-site, have had the opportunity to thoroughly study the characteristics of the water.



Riley Shutt, Riley Schutt, U.S. Sailing Team's IR&D Performance Analyst, is a member of the Outsight Network, run by the Autodesk Technology Centers during the COVID shutdown. Image courtesy of Autodesk.

"The site of the race is an important variable to take into account. A proper understanding of the site conditions allows the design team to target specific performance goals," says Franceschetti. "At the beginning of the campaign, a detailed analysis of many aspects of the location of the race is undertaken—in particular, the weather conditions expected at the time of the race. The statistical analyses made about the features of the location of the race, drive some of the key decisions of the competing yacht's design."

"The likely wind speeds, predominant wind direction and wave state are very important factors when optimizing boat design or selecting equipment," says Schutt.

While site conditions can be measured, they don't always reveal the winning formula. The weather on the day of the race may be atypical, contradicting the assumptions made during the design process. The crew's spur-of-the-moment decisions also affect the boat's performance.

"The difference in performance in these boats is small enough that you're never sure until you go out and race against another team," says Schutt. "Even if you put up an anemometer there and it says 12.6 knots, you still don't know the windshear or the twist, or how gusty it is, so these [factors] make it difficult to know exactly how you might perform compared to the others."

Simulation is most reliable when the digital model's behavior is validated with physical test data. This correlation

proves challenging with travel restrictions and limited access to the boat itself.

"Material testing is the primary task at the beginning of the campaign, with intense efforts dedicated to characterizing the many candidate materials. We want to make sure the simulation databases are fed with high-fidelity material properties," says Franceschetti.

"Initially, we planned to test most of the components, including the yacht itself, directly at the manufacturing site to monitor the outcome and potentially upgrade or put in modifications in the event things don't meet our design criteria or manufacturing quality benchmarks. Not to lose precious time during the relocation to New Zealand, we had to change some of our testing programs. Most of our components were finally tested on-site in Auckland prior to sailing," he adds.

HPC is Essential

Paul Stewart, VP of automotive aerodynamics modeling and visualization at Altair, is a naval architect, a long-time sailor, and an avid Sail magazine reader. The scope of simulation that competitive sailing teams undertake, he

explains, is enormous. It's something that demands more than a standard workstation.

"You're looking at how the air and water interact with the boat in real time, so it makes the problem more transient. It changes from millisecond to millisecond," he says. While CFD is more cost-efficient than tank testing, it still has certain constraints that limit how many runs can be executed.

"It might take 6 to 12 hours to run a 2-second simulation for a full car. The transient simulation of the flow fields for a 2-second event can produce half a terabyte of data. If you do 10 or 20 runs [for design variations], how do you consume that data?" asks Stewart.

In 2008, Schutt was a CFD Engineer for Cape Horn Engineering, located in Valencia, Spain. As a partner of Juan Yacht Design, the company was involved in yacht design for the Volvo Ocean Race and the America's Cup. By then, Schutt recalls, the use of CFD was already widespread among the participating teams.

"All the teams had big CFD groups. There was still tank testing and wind-tunnel testing, but a lot of the design decisions were made in CFD. Tank testing still requires a

Virtual Tow Tanks and Wind Tunnel

he America's Cup is a design race, and the battlefield has moved into the virtual environment," observed Dan Bernasconi, Head of Design, Emirates Team New Zealand.

An engineer with a PhD in mathematical modeling and aerodynamics, Bernasconi believes "the ability to accurately model and predict the performance of the yachts" is the key to success. For him and his colleagues, NUMECA Fine Marine, a CFD program for naval architecture, is the software tool of choice.

In a Q&A published by the software maker NUMECA, Nick Hutchins, CFD Specialist, Emirates Team New Zealand, revealed that the team had its own in-house computing cluster but also relied on subcontractors to "investigate a wider range of possibilities" ("ETNZ and NUMECA have a yacht to talk about!").

Hutchins gave credit in particular to the software's Wizard options. "That was a great asset. Without these tools, we could not have investigated such a number of designs," he said.

On the day of the race, speed will undoubtedly decide the winner, but in the design phase, the



focus is on fine-tuning the aerodynamics.

"We have to be sure that the foils will not break during the race! Also, cavitation or ventilation could increase the drag force, or just reduce the lift force necessary to make the boat fly. We have to make sure these phenomena are under control," explained Hutchins.

"The new major change in design for the next America's Cup is that we are going back to monohull, bringing completely different challenges in terms of hydrodynamics. I think we need to better understand the interaction between the flow and the structure deformation of the boat and its appendages," he added.

NUMECA FINE Marine functions both as a virtual tow tank and virtual wind tunnel. This is especially relevant to the current America's Cup as the rules restrict the number of real-world tank and wind tunnel tests among the teams.

→ MORE INFO

• NUMECA: www.numeca.com/product/fine-marine

scale model; by contrast, CFD can be done at full scale," he notes. "You definitely need HPC, whether cloud services or in-house. Nimbix is the Official Compute Partner to the U.S. Sailing Team and we rely on their cloud-based computational power. I think most America's Cup teams

have in-house HPC clusters."

Overall, the number of commercial CFD packages have increased across the industry. Many come directly from the leading CAD software vendors such as Autodesk, Dassault Systèmes, Siemens and PTC; and their simulation software

Optimization Accelerates America's Cup Design

he teams participating in the America's Cup compete as much on their design innovation as their sailing skills. Optimizing the design process, then, is critical for success. Two of the teams that participated in competition this year-the New York Yacht Club American Magic and Luna Rossa Prada Pirellileveraged ESTECO's mode-FRONTIER design automation and optimization platform.

American Magic relied on modeFRONTIER in each phase of the design process, from concept to refinement. The tool was used to streamline and automate the entire design process, perform optimization, and analyze and post-process results. The workflow developed using the tool was able to handle geometry changes during this process.

American Magic team engineers used several simulation soft-

ware tools for the foil and sail design, including geometry definition, force computation and boat speed estimation. The modeFRONTIER tool allowed them to automate the entire process.

The team used Mares to generate airfoil and flap geometries, along with a RANS-based tool to perform high-fidelity 3D simulation in the refinement and optimization phase. Throughout the process, they relied on CFD simulations to evaluate hydrodynamic forces and cavitation speeds. The Mares and CFD tools are coupled with modeFRONTIER via Easydriver nodes.

(You can read more about how the American Magic team used modeFRONTIER here.)





Italy's Luna Rossa Prada Pirelli team, meanwhile, also used modeFRONTIER in the design of the hull and foil of their AC75 Luna Rossa yacht, as well as for optimizing sailing techniques for the competition. According to Martin Fischer, Co-Design coordinator for the team, modeFRON-TIER helped in the preliminary design phase as the group did not have any experience with the new boat type introduced for the 2021 competition. They were able to use the simulator to create a takeoff sequence used across the initial design phase.

Fischer says the team used modeFRONTIER in the optimization of hull shapes, foil shapes, and to optimize sailing techniques, and they were able to explore a much wider design space in a relatively short period of time.

"We ran that in several loops,"

Fischer says. "In the beginning, we explored a very wide design space because we didn't know anything about these boats. Initially with less details, then we slowly introduced more details to describe the hull shape and reduced the size of the design space.

"All this took us about three months and without modeFRONTIER it would have been impossible," he adds. "It would have taken ages and we never would have found the very unusual hull shape that we found in the end. A hull shape came out that none of us had expected."

(You can read more about Luna Rossa Prada Pirelli and modeFRONTIER here.)

partners. This makes the transfer of the design geometry, representing the detailed shape of the boat, into simulation programs significantly simpler. Siemens Digital Industries Software is an Official Technology Partner of The U.S. Sailing Team and Schutt uses Simcenter STAR-CCM+ to analyze the team boats. There are also free programs available for preliminary checks during the conceptual design phase.

"There's a lot of utility in basic tools like XFOIL [from MIT], AVL [from MIT] and XFLR [Open Source]. For conceptual design decisions, it will get you going in the right direction," Schutt says.

Human-in-the-Loop Simulation

In September 2020, New Zealand's broadband and mobile service provider Spark announced the opening of the Spark 5G Race Zone, a virtual boat racing experience. The attraction is "powered by Spark's 5G technology and created alongside partner Emirates Team New Zealand (ETNZ)," according to the press release.

"The 5G Race Zone gives visitors the opportunity to feel, create, learn and even smell all things sailing-without getting on the water—by bringing together the best of sailing and technology in seven fully interactive zones."

In 2018, Artemis Technologies, a Northern Irelandbased firm, developed and released another simulator for sporting teams.

"The 4.5-meter high, 210-degree screen, which conveys images from three laser phosphor projectors, is wrapped around a physical platform similar to those used for flight and motorsport simulators, providing an incredibly immersive experience," according to the announcement. "The new simulator has been developed over the last 12 months, and is a continuation of the work undertaken by Artemis Racing during the last America's Cup."

Though CFD offers a way to analyze the aerodynamics of specific designs, it doesn't offer a way to see how the crew's real-time decisions and teamwork affect the boat's behavior. Immersive simulators like those from Artemis Technologies allow the teams to commandeer a virtual boat to test its potentials in different weather and wave conditions. It's a method that Schutt believes more sailing teams are exploring.

"I think we will see this time that teams are using humanin-the-loop simulation—a real-time environment where you can virtually sail the boat. With this method, the sailors learn the reflexes required to keep the boat flying. Ultimately, you still need people to learn to keep the boat stable, on the water and airborne," he says.

"In the previous programs, we looked at a lot of the primary issues like the mainsail, the foresail and the shrouds,"



says Stewart. "It would have been interesting to study how the position of the sailors along the deck and rig affected drag and lift. The teams had theories and intuition, but they couldn't see it [with flow fields]."

When INEOS TEAM UK was building its first boat, it built a wooden mockup of the cockpit to let the sailors see and approve the layout. The same approach was used in the second boat to tweak the design based on the sailors' feedback.

"The sailors have been included in decisions across the design process, including, for example, the foil controls and hull design. They are, after all, effectively the end users of our design process. Throughout the design process, it has also been useful to have the sailors sail the virtual boat in the simulator and give us their feedback," says Starr. DE

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

MORE INFO

Altair: Altair.com

Artemis Technologies: ArtemisTechnologies.co.uk

Autodesk: Autodesk.com

• Nimbix: Nimbix.net

Siemens Digital Industries Software: <u>SW.Siemens.com</u>

• Spark 5G Race Zone: Spark.co.nz/5g/home/race-zone

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Advanced CFD at the helm in Competitive Sailing

New rules in America's Cup encourage virtual testing.

BY KENNETH WONG

n the paper published by the American Institute of Aeronautics and Astronautics (AIAA) titled "CFD Design Studies for America's Cup 2000," authors Bruce Rosen, South Bay Simulations; Joseph Laiosa, Fluid Motion Analysis; and Warren Davis, Jr., AIAA member, traced the history of the use of computational fluid dynamics (CFD) in America's Cup boat races back to the 1990s.

"CFD for yachts started to gain importance in 1983, when John Bertrand on Australia II with its high-tech winged / inverted keel took the cup from Dennis Connor on Liberty, breaking the longest winning streak in the history of sports (132 years). Technology, from any and every design aspect, was sought to bring the cup back to the U.S., and CFD benefited from that urgency. From our perspective, that movement began our involvement with the design program for Dennis Conner's 12-meter yacht Stars and Stripes '87. For that campaign, vortex lattice, panel codes and even some initial Navier-Stokes methods were all brought to bear on the underwater design," the paper stated.

In the paper "CFD in Sport: a Retrospective, 1992–2012" (bit.ly/36JNnlR), published by the International Sports Engineering Association (ISEA), the author R. Keith Hanna, Mentor Graphics, described CFD generally available for yacht design in the 1990s as "Simplified 3D geometries, tri[angle]/tet[rahedral] meshes, single processors; free surface & mesh-size restrictions, [completed] in weeks."

"The level of CFD use in boat races has been increasing," says Dr. Paul Stewart, vice president, automotive aerodynamics modeling and visualization at Altair. "Thirty or forty years ago the codes were very crude and simple. You could simulate the keel and sails, just like you would an airfoil, in steady state with simplifications."

Mixing Water and Wind

As simulation complexity increases, so does the reliance on a higher class of hardware, offering much more capacity than personal workstations.

"In the last 10 years, the trend has been to use large com-

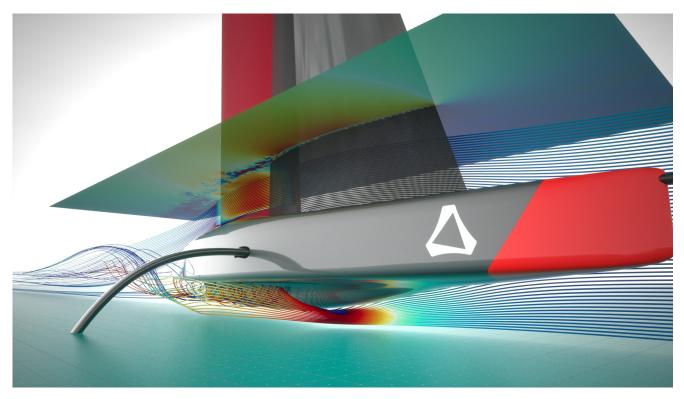
pute power and study the simulation results as responses surfaces. You look at the parametric shape changes in the design space, study them statistically to see how they work together and figure out which combination works best. You can only do that for complex CFD problems with large-scale computing," says Stewart.

"If you are simulating a small powerboat, the domain you are solving is quite small, but when you are solving for a sailing boat, where the wind really matters, you have a massive domain to solve. The atmospheric wind matters quite a lot and solving and understanding how we can best get thrust from that, needs a lot of cells. Then on top of that, you also have the water interface that you need to solve," says Max Starr, CFD engineer for INEOS TEAM UK, a contender in the 36th America's Cup. INEOS TEAM UK gets support from Siemens Digital Industries Software with the company's design, data management and simulation software.

Rules Encourage Virtual Testing

To minimize cost for participants, America's Cup organizers have prohibited tank testing, wind-tunnel testing and similar fluid dynamic testing. The AC75 Class Rule published in March 2018 puts "strict limitations on the number of components that can be built, including hulls, masts, rudders, foils and sails, thus encouraging teams to do more R&D in simulation and subsequently less physical construction and testing." These restrictions encourage more virtual testing, usually done in CFD.

"It would have been a lot more difficult 20 years ago if we had the same rules now," says Starr. "We can have a lot



Traditional boats balance sail aerodynamics against the hydrodynamics of the hull and appendages. Now that boats fly, the hull is part of the aerodynamic system. Much like the ground effects of a road vehicle, the air flow between the hull and water is a significant new design problem and opportunity for the participants of the America's Cup and other boat races. Image courtesy of Altair. Model created with Altair Inspire Studio, simulated with Altair ultraFluidX, and rendered with Altair Inspire Render.

more faith in the computational models now than we could have had 20 years ago."

"Virtual prototyping has become the way to get an advantage on the competitors and perfect the design," notes Mark Fischer, director of product management at PTC. "HPC (high-performance computing) plays a huge role. Aside from the cluster, a competing team might have at its disposal, other cloud resources and on-demand services, like those from our partners Microsoft and AWS, [that] play an important role. They were not as abundantly available as they are now."

PTC offers Creo Parametric, a general design program, plus Creo Simulation Live and Creo Flow Analysis to further refine the design using finite element analysis (FEA).

Riley Schutt, U.S. Sailing's performance analyst and fluid modeling and design specialist, says the types of simulation that America's Cup teams do usually demand HPC.

"You definitely need HPC, whether cloud services or inhouse. Nimbix is the Official Compute Partner to the U.S. Sailing Team and we rely on their cloud-based computational power. I think most America's Cup teams have in-house HPC clusters," he remarks.

GPU's Role in the Race

Traditional CFD is done with Navier-Stokes methods or even panel codes, typically on CPUs, according to Stewart. But the development of the Lattice Boltzmann method

opened new possibilities. It was a method particularly effective with distributed computing or clusters.

"The Lattice Boltzmann code is compute-intensive, because it works out changes in very fine voxel spaces at every time step, so it takes a lot of memory," says Stewart. "When you apply GPUs (graphics processing units) to it, it allows you to tackle large problems."

GPU maker NVIDIA, for example, works hard to convince commercial CFD software developers to write GPUaccelerated codes in its compute unified device architecture programming environment. Ansys Fluent is one example of GPU acceleration, and has model flow, turbulence, heat transfer and reactions for industrial applications.

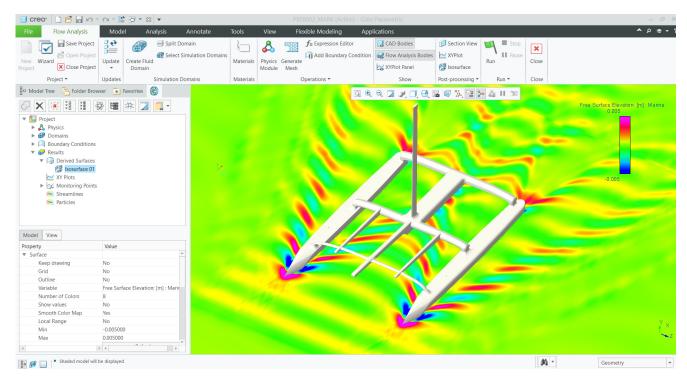
"Ansys Fluent runs up to 3.7X faster on GPUs, dramatically reducing time to solution from weeks to days," NVIDIA states.

However, not all simulation tasks can benefit equally from the GPU.

"CFD codes do not scale very well on GPUs, especially when you are simulating both water and air," says Starr. Starr and his colleagues from INEOS TEAM UK use Siemens' Simcenter STAR-CCM+ software for CFD.

No Free Lunch in the Virtual World

Virtual tests and simulation cost much less than building physical mockups and conducting tank testing, but the pro-



PTC offers PTC Creo for design construction, along with Creo Live Simulation and Creo Flow Analysis for FEA studies. Image courtesy of PTC.

cess still exacts a toll—in time and computing cycles.

"The whole setup involves taking the CAD model of your design idea, to creating a surface mesh, and then the volume mesh around that [to represent the air and water interacting with the boat]—that's just preprocessing. Then you have the simulation itself," explains Stewart.

"In comparison, it might take 6 to 12 hours to run a 2-second simulation for a full car. The transient simulation of the flow fields for a 2-second event can produce half a terabyte of data. If you do 10 or 20 runs [for design variations], having the compute power to consume that much data is important," Stewart says.

"When we use CFD in the America's Cup, although we do have a lot of repetitive simulations, there are a lot of one-off simulation studies as well. Especially now, with this unique and new class of boat, we are still trying to understand that as well. That means there are a lot of one-off what-if studies that we will do. You do want to have a standard library of simulations just to churn through different designs and different scenarios," he adds.

Hanna, the author of the paper "CFD in Sport" (ISEA), points out that in 2012, CFD for yacht design had improved to allow "Full 3D models, HPC, supercomputers, moving hybrid mesh, overtaking, free surface, [results] in days."

That's much better than the weeks it took in the 1990s to get the results, but with the clock ticking away before

the race, the number of days available to explore different ideas, commit to a specific concept, then manufacture the boat, is finite. **DE**

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

MORE INFO

• Altair: Altair.com

Ansys: Ansys.com

• NVIDIA: NVIDIA.com

- "CFD Design Studies for America's Cup 2000" paper: bit.ly/3q5AB8X
- "CFD in Sport: a Retrospective, 1992–2012" paper: bit.ly/36JNnlR
- PTC: PTC.com
- Siemens Digital Industries Software: SW.Siemens.com

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GPU-Accelerated Visualization Makes its Mark

More software solutions are taking advantage of real-time ray tracing and enhanced visualization made possible via the GPU.

n 2018 NVIDIA made headlines when it announced its RTX GPU family would enable hardware-accelerated real-time ray tracing and AI denoising. However, GPU acceleration was still not widely supported for these applications in the engineering and design market.

Over the past 12 months, however, the real impact of GPU-accelerated rendering is fully coming to bear. There are now dozens of 3D applications that support the RTX platform. In the engineering space, software solutions like Siemens NX RT Studio, SOLIDWORKS Visualize, Luxion KeyShot, and products from Ansys, Autodesk and others have unlocked entirely new workflows by allowing users to access rapid rendering and visualization tools.

When Luxion announced that its KeyShot product would support GPU-accelerated ray tracing via NVIDIA technology back in 2019, it was heralded as an important milestone in enabling new levels of rendering and visualization performance.

That performance is taking another dramatic leap forward with the release of both KeyShot 10 and the new NVIDIA RXT A6000 GPU. According to the companies, the combination fo KeyShot 10 and the new GPU could potentially increase performance significantly. According to Bob Pette, vice president of the professional visuzlation product group at NVIDIA:

"Luxion, makers of the popular KeyShot product visualization tool, is seeing close to triple the performance using the NVIDIA Ampere architecture. The integrated benchmark in the free KeyShot Viewer gave 34.7 on the NVIDIA RTX 6000 and 88.8 on the NVIDIA RTX A6000. In the upcoming KeyShot 10 release the performance on the A6000 was even better at 95.6 — that means the A6000 is 95.6x faster than the CPU baseline."

According to Adam Hughes of Goengineer.com, the most recent SOLIDWORKS releases have taken advantage of the NVIDIA RTX platform in SOLIDWORKS CAD, eDrawings Pro VR, and Visualize in ways that can greatly improve productivity.

"We are seeing an incredible trend in the software world where companies are changing their code and taking advantage of multi-threaded GPU processes," Hughes says. He adds that the improvements are not just incremental, but orders of magnitude better than previous releases.



SOLIDWORKS Visualize 2020 rendering with NVIDIA Quadro RTX 6000, 1,000 passess in 2 minutes, exhibiting a ~30% speed improvement compared to Visualize 2019 SP4. Image courtesy of SOLIDWORKS.

In SOLIDWORKS CAD, for example, GPU acceleration has allowed users to work with models that have much greater levels of detail. The photorealistic VR in eDrawings Pro has accelerated a number of design processes. "Now that we are all working remotely and we cannot be in the office holding prototypes, having design reviews in VR actually speeds things up," says Mike Geyer, manufacturing industry strategist at NVIDIA.

SOLIDWORKS Visualize has also made it possible to quickly create highly accurate visuals for design reviews and approvals throughout the design cycle, as well as for preparing marketing collateral in advance of actual prototyping. That type of GPU-based real-time ray tracing and AI denoising simply was not possible prior to 2018. "Now that we have GPUs with more than 3G of VRAM, you can turn on that denoising capability and achieve 10X rendering speeds," Hughes says.



Low Code Aims to Democratize Thread Development

The technology shows promise in overcoming many hurdles tied to realizing the full potential of the digital thread.

BY TOM KEVAN

s digitalization gains momentum, the engineering community, enterprises and manufacturers are up against a brick wall. To move forward, they must come to terms with a new set of market and technology realities.

For organizations that implement digital threads, the obstacles take the form of two seemingly irreconcilable truths: the increasing need for software customization and the absence of the required IT resources that develop the specialized code.

To avoid this impasse, software companies—especially product lifecycle management (PLM) vendors—have reduced their reliance on traditional software development practices and are beginning to increase use of low-code development. Part of the appeal of this technology is that it promises to sweep aside many of the obstacles that hinder digital thread's full potential (Fig. 1).

Breaking the Bottleneck

To understand how low-code development facilitates digital thread creation through software customization, it helps to examine the forces at play and the constraints with which the technology must contend.

Many companies rely solely on their IT departments to perform application development, customization and integration. This approach is based on the principle that programming is a specialized skill that only a guild-like workforce can perform. This approach, however, creates three problems that hinder companies' efforts to develop custom applications and achieve optimum digital thread performance.

Taking this tack isolates programmers, separating them from application end users, which often forces programmers to rely on poorly defined requirements and use cases to channel and shape their creations.

To rely on programmers for all software development also stretches IT resources. The reality is that trained and experienced programmers are increasingly in short supply, and the situation will only get worse.

"The explosion of apps has made it impossible for IT teams alone to maintain and build new apps demanded by businesses," says Daniel Lahl, global vice president of product marketing at SAP.

This means that users are faced with two unacceptable choices: they either have to wait long periods of time before the resources become available for the software to be developed, or they simply have to do without the tools.

The use of a traditional programming approach also means that thread developers with specific business and design expertise, but a lack programming skills, have no way of applying their expertise in the development of the special applications that they require.

This means companies must find a way to offload some of the software development responsibility from their IT departments. To this end, PLM vendors are turning to low-code development. They believe this will create a path to democratization of the application development process, which will in turn mitigate the programming talent shortage, leverage domain knowledge that has been untapped until now, and simplify and shorten development cycles.

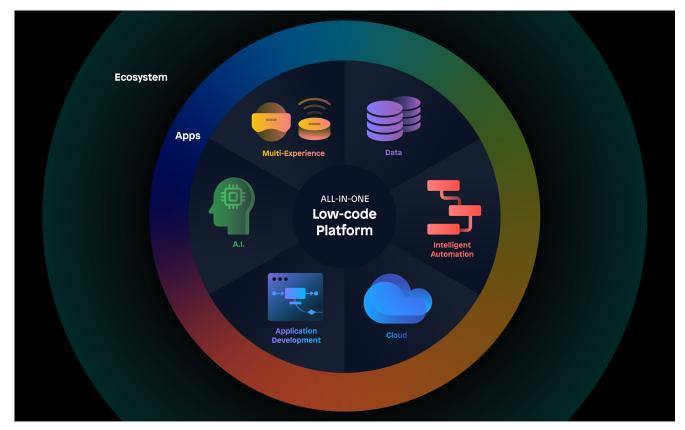


Fig. 1: LCDP promise to simplify application development by applying programming abstractions via a visual interface, compiling code using drag-and-drop components. Image courtesy of Mendix.

One More Hurdle

The development of custom PLM/digital thread applications has been further complicated by the way PLM software providers have viewed customization.

"Historically, PLM vendors designed their software to run out of the box—consisting of many different technology stacks from the same vendor," says Mark Reisig, vice president of product marketing at Aras.

To support this rule of thumb, PLM vendors contended that companies should adhere to what is known as the "80/20" rule, where customization is limited to 20% of the entire solution.

Unfortunately, this practice hampers digital thread developers' ability to adapt to changing business, regulatory and technology requirements. In addition, waiting for PLM vendors to provide critical functionality causes PLM deployments to be frozen in time.

What Are LCPDs?

All these obstacles drive home the point that customization is required to get the best fit between a deployable PLM system and specific application needs, and low-code development platforms (LCDPs) support this transition.

Despite the fact that low-code development tools are about a decade old, for many, it represents a new market force, and they are not clear on what the platforms do. Essentially, LCDPs provide GUIs that allow tech savvy users to create custom-designed applications instead of requiring them to use traditional programming tools and methods.

In essence, LCDPs replace coding by enabling the user to compile the code visually with drag-and-drop UI components. These platforms automatically generate all of the application's components-including frontend and backend code and configuration files—based on standard best practices.

"Because of the visual modeling, or drag-and-drop development options, a maker no longer must be a professional developer who only works in a full-code environment," says Bill Boswell, vice president of cloud marketing at Siemens Digital Industries Software. "Now, with lowcode, business and domain experts—whether they have developer experience or not-can contribute to, or fully build, a functioning application."

DIGITAL THREAD || Low Code

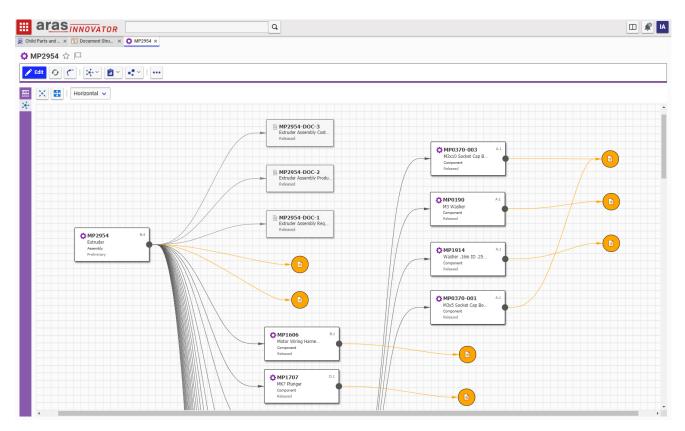


Fig. 2: Aras Innovator, a low-code development–based PLM system, is used to create a fit-for-purpose application. The resulting software shown on the above screen provides a Graph Navigation view containing dynamic links that allow users to visualize and navigate a digital thread of product information.

Image courtesy of Aras.

These platforms reduce the amount of time it takes to create software, so that business applications can be delivered more quickly, and a wider range of people (sometimes called citizen developers) can contribute to software development.

When used to build digital threads, LCDPs allow users to access and integrate data from the various repositories and silos, in a range of formats and languages, using RESTful APIs and platform services (Fig. 2).

"This level of software development and integration automation helps tech-savvy business users—those who know their business and processes best—to build their own apps and drive their own experiences with low-code capabilities," says Lahl. "Business users are enabled to create fit-for-purpose departmental apps with clicks-or-code and without IT intervention, freeing-up IT bandwidth to focus on business-critical processes and tasks."

Empowering Digital Thread Developers

One of the main ways LCDPs enrich PLM/digital thread projects is that they allow more stakeholders to participate fully in the development process. This not only brings the full weight of the team's multidiscipline expertise to bear on

digital thread development and maintenance, but it also provides them with access to a fuller range of data sources.

"With low-code technology, we can empower PLM users working on various aspects throughout the digital thread to create applications themselves that solve their business problems, regardless of their technology background," says Boswell. "For example, a PLM business user, who is an expert in their area, may need to gather data from multiple systems. They can now create a low-code app to do this, pulling in data from PLM and other systems."

The application can also be a way to complete a digital thread with the systems and data sources in place. Because low-code platforms enable integration with a broad range of systems and data formats, the applications can connect to data and simultaneously extend existing systems that are a key part of a digital thread. In doing so, the applications open the door to the critical feedback loop that comes into play when a PLM user can get data from production and performance sources back to designers in real time.

LCDPs also give thread developers access to an expanded toolset and help them to create more efficient relationships between nonprogrammers and the IT department.

DIGITAL THREAD III Low Code

"By empowering business experts and design engineers to directly translate their knowledge into executable models, IT can establish a partnership with the business that best leverages the expert skill sets in both domains," says Lahl. "Design engineers can quickly model digital threads using low-code development tools, while IT can provide the expertise to scale these efforts into larger solutions, such as complex digital twins or complex business processes that span the value chain."

LCDP Shopping Guide

As exciting as the technology sounds, it is important to remember that not all LCDPs are created equal. So, it is worth noting some features to look for when organizations select a low-code system.

The top considerations are the architecture and automation features. Both of these are important because they determine the platform's agility. The very nature of digital thread and digital twin require that application development platforms be able to easily meet evolving user demands, changing processes and the addition and deletion of systems with which the platform must interact. All these factors demand modifications to the original software, and this is where LCDPs can help or hinder developers of digital threads.

"Low-code development can play a huge role in adapting to these changes," says Aras' Reisig. "An industrial low-code platform that is resilient and agile can begin to meet the challenges of today's modern business and societal fluctuations."

Automation features such as the drag-and-drop options in the UIs define the accessibility of the development tools for users just beginning to use the software.

An LCDP must also be flexible enough to support multiexperience applications, ensuring that users can develop software that can be deployed various devices. This will help users to rapidly scale their applications across a range of devices and platforms.

"Because data within a digital thread can come from products as well as the people creating, using, testing and servicing those products, it is important that the app can function in the exact experience the user needs to get or add the data to the thread," says Boswell. "So, if a service repair person is out in the field using a mobile device, the app should simultaneously work as well on the mobile as it does for the product designer working on a desktop."

LCDPs must also facilitate software test and validation, particularly when working on digital thread projects. This means providing complete application modeling tools.

"Developers of digital threads should look for LCDPs that allow all tiers of an application to be modeled," says Lahl. "Many platforms have a 'closed' concept of an application, which may be fine for developing conventional apps that have a mobile or web interface. But for developing digital threads, the development platform must

support robust modeling of physical concepts in data models and business logic. The platform must be capable of exposing these as micro-services, not just as full-stack apps. This allows these digital threads to be composed into more complex networks or used in solutions with multiple user touchpoints."

Sill Carving Out Its Niche

If engineers listen to LCDP providers, they may come away with the impression that non-programming professionals from the design and business communities will be the primary beneficiaries of the technology. Take a closer look at market research, and conclude that the market is still deciding LCDPs' place in the digital thread toolset.

In 2019, a worldwide Forrester survey found that 37% of developers were using or planning to use low-code products. By mid-2020, the research firm predicted that the number would rise to more than half of developers. What is clear is that while IT professionals have begun to take LCDPs for a test drive, they have not totally embraced the technology.

Based on a March 2019 survey of 3,300 IT professionals, OutSystems' "State of Application Development Report, 2019/2020" (bit.ly/3aGu667) reported that 49% of organizations have citizen developers at their company. Of those, 41% use low-code platforms.

As organizations weigh these statistics, and it becomes clear that low-code technology's role has yet to be defined. The question to be decided isn't whether the platforms offer value. What has to be decided is who will be the technology's primary beneficiaries: IT professionals, citizen developers or both. DE

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MORE INFO

- Aras: Aras.com
- Mendix: Mendix.com
- SAP: SAP.com
- Siemens Digital Industries Software: SW.Siemens.com/en-US

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Generative Design:

A Heavyweight for Lightweighting with Additive

The combination of generative design software and AM technologies is proving to be a go-to force for lightweighting and parts consolidation strategies.

BY BETH STACKPOLE

he Silicon Valley Hyundai engineering team that works on Elevate, a walking concept car, is continually coached as if they're on a perennial diet. Attention to weight is the team's marching orders: If someone specs a connector to send a signal, it raises automatic questions about if a wireless signal is sufficient. It's the same

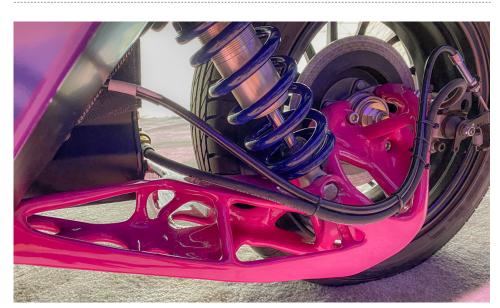
design mentality for fasteners—use glue or explore parts consolidation—and even reconsider paint when it's possible to substitute dyed plastic.

The team, part of Hyundai Motor's CRADLE corporate venturing and open innovation business, is designing a new class of electric ultimate mobility vehicles (UMVs) from a

blank slate with the goal of shaving 500 kg from conventionally-designed vehicles of a similar size. Elevate, along with the Tiger cargo transport variation revealed in February, must climb a 5-foot wall, walk over diverse terrain and drive at standard highway speeds—all while keeping its body and passengers level.

With such specific objectives, lightweighting is one of the bedrock design strategies, and generative design tools paired with additive manufacturing (AM) technologies have become a invaluable staple.

"Every ounce counts-nothing is off limits," says John Suh, Hyundai vice president and head of Hyundai CRADLE, who is also the executive spon-



As part of a generative design lightweighting exercise, Arcimoto and XponentialWorks reduced the weight of a swing arm part by about 34%. Image courtesy of XponentialWorks.



Generative Design capabilities in Autodesk Fusion 360 platform are helping to explore lightweighting opportunities for Hyundai's Elevate Ultimate Mobility Vehicle. Image courtesy of Hyundai.

sor of the UMV project and founder of the car manufacturer's New Horizons Studio, an innovation incubator.

"We're designing something that has never been designed before so we need to look at new ways of solving the problem. If we use the same methods, there's less chance of getting something that hasn't been done," he says.

A Synergistic Relationship

The Hyundai team, like countless engineering organizations across industry sectors, prioritizes lightweighting design strategies as a way to reduce costs, improve product performance and simplify production through parts consolidation.

Generative design software, known for its ability to churn out organic, nature-inspired shapes, is a natural force for lightweighting parts or rethinking existing components with the goal of reducing mass and materials without impact to structural integrity.

When engineering firms pair it with additive manufacturing (AM), which can output the organic shapes not possible with conventional manufacturing methods such as casting or injection molding, they can find a sweet spot to achieve lightweighting goals.

"AM and generative design are two sides of the same coin," says David Busacher, senior engineering consultant with Stratasys. "AM is adding material where it needs to be, and generative design is adding design where it needs to be. "They really are the consummate match because with generative design, a lot of the complex geometries can't be traditionally manufactured."

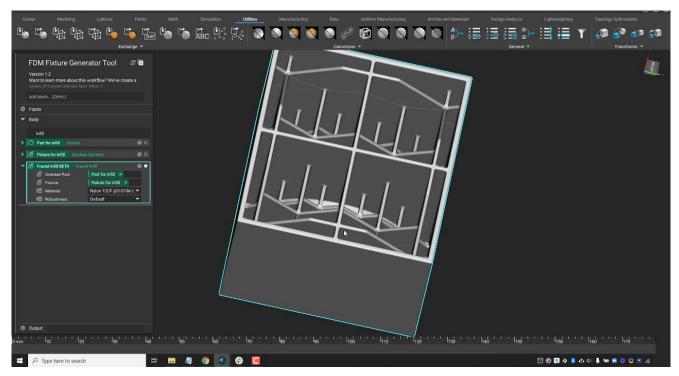
The combination of AM and generative design is instrumental for parts consolidation, another design strategy directly relevant for achieving lightweighting objectives. The opportunity to come up with unique shapes that fully integrate multiple parts into a single assembly has huge ramifications for reducing weight, costs and more, according to Avi Reichental, founder, CEO, and chairman of XponentialWorks.

"The ability to harness algorithms with infinite computing power along with AM opens the possibility for significant lightweighting, significant leaning of the supply chain, reduction of part counts, and increasing the structural performance and overall product performance," Reichental says.

XponentialWorks put the dynamic duo to work in a partnership with Arcimoto, a startup that develops a line of lightweight, electric fun utility vehicles (FUVs). The joint project is experimenting with different 3D printing technologies and the CogniCAD generative design software from Paramatters to decrease the overall vehicle weight with lightweighted components. So far, the team has reduced the weight of a rear swing arm by 34%, an upper control arm by 52% and a brake pedal by 49%, Reichental says.

"In 30 days, we dropped 30 lbs. out of the product, which is a significant reduction in weight for a vehicle in this class," says Mark Frohnmayer, Arcimoto CEO.

While the team targets specific parts, the next step is to do an optimization pass to reduce the weight and complexity



nTopology and Stratasys' FDM Fixture Generator streamlines the design of custom jigs. Image courtesy of Stratasys.

of the overall vehicle through part re-examination, Frohnmayer says. The original vehicle weighed in at 1,300 lbs. and the goal is to get to 1,100 lbs. to target the micro-mobility class. While AM was optimal for creating early prototypes, Frohnmayer says the company will have to evaluate cost trade-offs between AM and more traditional manufacturing technologies for mass production with help from the XponentialWorks.

Even without AM as the ultimate output measure, generative design can have a big impact on lightweighting. The software automates the iteration process—instead of having a person manually make decisions on where to remove or add material, the algorithm automatically goes through the process, based on input parameters and constraints and building and iterating the outcomes.

At the same time, however, engineers need to understand that many of the lightweight shapes that generative design tools produce aren't necessarily a candidate for 3D printing right out of the gates—often, they are used to jumpstart the process by giving engineers a guidepost for refining and evolving ideas using their own institutional knowledge.

"The process informs engineers from a physics perspective about what to cut out—otherwise the engineer has to put their finger to the wind and start carving out a design," Busacher says. "It gives ethos to what the next iteration will be."

Stratasys is doing many things to build confidence in AM

for producing lightweight, and potentially generatively created, designs. Quality is key generative design and AM adoption, and Stratasys has built confidence via the F900 printer and materials, according to Busacher.

In addition, through a partnership with nTopology, the company released the FDM Fixture Generator, which combines Stratasys' 3D printing expertise with nTopology's generative design and automation capabilities for a tool that streamlines the design of fixtures for producing lightweight parts.

Autodesk continues to improve Fusion 360, specifically in the area of generative design, to make it the central tool for AM, according to Paul Sohl, product marketing manager for the company.

This effort includes support for the 3MF file format, an XML-based data format specific for AM that stores more granular information than the STL format, as well as a partnership with Xometry to incorporate a price and quote engine directly into the CAD platform; the engine also helps optimize the complementary technologies for production use cases.

For Dassault Systèmes, generative design and AM are wed through the 3DEXPERIECE platform, which breaks down the barriers that have traditionally handicapped these design workflows via a unified data model and common user experience, explains Colin Swearingen, industry process

DESIGN ||| Generative Design

consultant at Dassault.

Traditionally, different people use different tools throughout the design workflow to achieve lightweighting-for example, CAD, CAE and optimization software—and engineers have to tie together the different models and data in a streamlined workflow to reap the benefits.

"It's about tying together all aspects of engineering into a common environment so you can accomplish tasks on a single data model," Swearingen says.

Challenges Ahead

Lightweighting with generative design software and AM is relatively new ground, so most engineering organizations are still feeling their way around to choose the right tool, define optimal workflows and code best practices. One of the biggest miscues organizations make is to over rely on technologies, treating both as a black box that magically outputs the consummate lightweight part at the press of the button. The truth is it's much more complicated than that.

Engineers must fully understand and define their lightweighting goals and constraints to properly direct the generative tool software as well as understand material properties, support structures and what's going on inside 3D printers so they can produce optimized, high-quality parts.

"Algorithms are not yet at parity with respect to what people can achieve, especially in the area of anticipated loading conditions," says Patrick Dunne, vice president of application development for 3D Systems, describing a tool's propensity to remove all excess material without the benefit of human guidance.

"If you're approaching the very edge of catastrophic failure, you need to still have the human element of review and expertise. Algorithms are really just tools you use; you can't rely on them 100 percent," he says.

Taking a systems-level approach to lightweighting is another important best practice, along with rethinking the design process so that engineers and analysis specialists are working more collaboratively as part of a seamless and automated workflow, says Brad Rothenberg, CEO of nTopology.

Instead of 3D printing existing parts, the right strategy is to re-envision those parts through the lens of consolidation to find lightweighting opportunities. Similarly, a lot of companies zero in on a single part redesign or component instead of looking at the entire system for lightweighting opportunities.

That reluctance to change points at the number one challenge organizations face as they pursue lightweighting strategies: The organization at large simply isn't open to new ideas, tools or design methodologies. For Hyundai, addressing the culture is somewhat easier given that Suh's group is part of an innovation center and is tasked with building something entirely new from scratch.

Still, Suh emphasizes the importance of educating and promoting a new mindset, with the understanding that it's all new terrain and unfolding as a work-in-progress. That's certainly true with how Suh is proceeding with AM and generative design. The two technologies have advanced the lightweighting ball on the initial scale models, but Suh doesn't rule out using conventional manufacturing options if they prove to be more effective.

"Begin with all the options on the table for design, whether that's traditional or generative design, and also consider AM as an option," Suh says. "From that point, it takes experimentation and thinking through the practical limitations in terms of the materials available for AM, the design tolerances we can achieve through AM, and the economics." DE

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→ MORE INFO

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• Autodesk: Autodesk.com

Dassault Systèmes: 3DS.com

• Hyundai CRADLE: Cradleinc.com

• nTopology: nTopology.com

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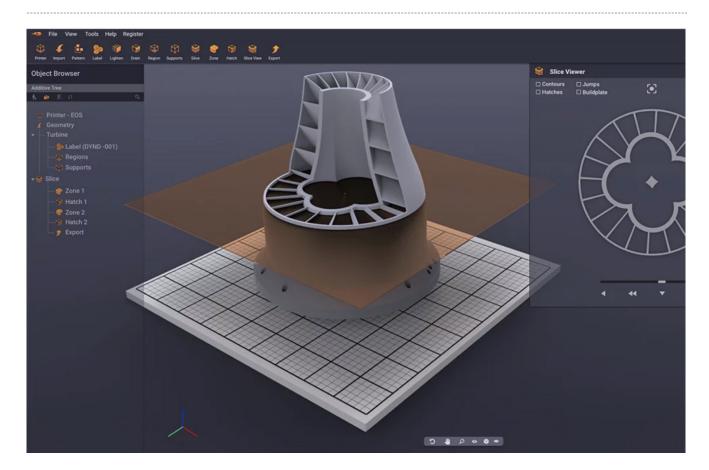
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GPUs Invade Product Development

Parallel processing continues to bring benefits to CAD, simulation and VR work.

BY RANDALL S. NEWTON

he first generation of CAD and CAE software for PCs was designed to do all the calculations on the CPU. Graphics processing units (GPUs) were only for accelerating graphics displays. It would be years before NVIDIA and AMD added sophisticated parallel processing hardware, at first in support of new video games. It didn't take long for CAD/ CAE software developers to realize there were new capabilities in GPUs that they could use.





There was one problem: CPUs are designed as sequential processing units. Engineering applications constantly solve challenging algorithms. The sequential, evolving nature of engineering and design work matched with the singlethreaded nature of solving algorithms. So in virtually every CAD, CAE and CAM program, the CPU did the mathematical heavy lifting and the GPU delivered results to the screen.

To this day, CAD programs mostly operate in a serial, single-threaded mode, while GPUs use a parallel approach to processing graphics, and perform the same calculations millions of times to achieve graphics realism. CAD vendors can't just toss away generations of work in sequential processing.

Nonetheless, engineering software vendors have found ways to harness the tremendous performance that GPUs offer and use the hardware as a tool for product development engineering.

New Uses for Engineering Data

Engineering workflows have evolved from manual processes to computer-based designs that are more realistic and tangible. Today, there are forms of engineering work that did not exist 10 years ago.

Computation engine is new software designed to be a next-generation geometry kernel for engineering applications. The software will simultaneously support a variety of geometry types including surface meshes, B-reps, volumetric data, voxels and tetrahedral meshes. It is the first geometry kernel written to support GPUs. Image courtesy of Dyndrite.

"Visualization of design in VR and democratization of simulation are really interesting topics that can drive discussions around GPUs," notes Chris Ramirez, strategic alliances manager at Dell for manufacturing and construction.

"Up until recently, mainstream engineering tools were all CPU-bound on single threads," notes Andrew Rink, a senior member of the marketing team at NVIDIA. "But now designers and engineers use multiple design tools, and there are new capabilities that require much more graphics acceleration. Someone might be using AutoCAD but want to drop the model into VR or use a physically based rendering tool. This completely changes the dynamic. If someone is thinking about real-time simulation or VR, they need a higher-end GPU."

"Throughout all design work, we are seeing two trends," says Glen Matthews, senior manager of product management at AMD. "VR/AR is one. The other is rendering within design; it shortens the production cycle. Both trends are about using visualization to design products faster."

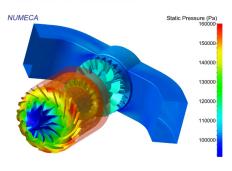
A GPU Convert

Henrik Jensen co-founded software company Luxion to push the boundaries of 3D rendering. It demonstrated the first interactive ray tracing application in 2006. The company's primary product, KeyShot, creates physically accurate renderings of 3D objects with the use of global illumination algorithms. It has become popular for professional use cases, including product development.

When Luxion began, GPUs were on the market for a few years, but were primarily for faster display, not algorithmic processing.

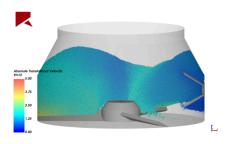
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Non-Linear Harmonic method



KJ66 static pressure

Numeca says its non-linear harmonic of solving transient behavior gains "three orders of magnitude" solving speed when run with GPUs. Image courtesy of Numeca International.



A simulation in Rocky DEM 4 of 10 million particles in a granulator, colored by their translational velocity. Image courtesy of Rocky ESSS.

"KeyShot used complex algorithms, and they ran well on the CPU. But they didn't map to GPUs," says Jensen. So the company focused its development work on CPU use.

In 2018 Jensen attended an NVIDIA event and saw the prototype of the RTX specification, which included hardware support for ray tracing, the most common form of illumination for 3D rendering. Jensen was impressed by how far GPUs had come since 2006. The company decided to "start fresh with new tech" for KeyShot 9, released in 2019.

"Starting with the newest generation of NVIDIA technology gave us an advantage," he says.

But Luxion did not abandon CPU-based rendering, for two reasons. One, says Jensen, is the large base of existing KeyShot users that do not use the latest GPU technology. Two, AMD had big advancements in CPU technology.

"AMD Threadripper is amazing," says Jensen. The best combination of CPU and GPUs, Jensen says, would be an NVIDIA RTX-class GPU and an AMD Threadripper CPU.

"For most product scenes the GPU does deliver blazing performance, but for highly complex scenes with a lot of geometry and textures, the CPU with access to more memory becomes competitive," says Jensen.

A CPU like Threadripper is also preferable over GPUs in scenes with highly divergent shading behavior. On a Luxion benchmark designed to test such shading, Jensen says the Threadripper 3990X is three times faster at rendering the scene than the NVIDIA RTX 6000. Precision is another factor. The CPU uses double-precision 64-bit floating point calculations, while the GPU uses single-precision 32-bit floating point calculation.

"This does limit the accuracy in large scenes, and can lead to gaps or inaccurate shading," notes Jensen.

KeyShot on a CPU has one more trick, Jensen says—direct ray tracing of NURBS. "Direct NURBS ray tracing is beneficial when working with large models that contain small parts."

All in at Ansys

Engineering simulation and analysis specialist Ansys has used GPU acceleration in its products since the release of Ansys 15.0 in 2014. Today, nine products in the Ansys portfolio support GPUs for faster computational performance.

Discovery Live offers interactive, instantaneous simulation results for up-front design exploration. Mechanical uses GPU acceleration in several of its solver algorithms. Fluent and Polyflow use GPUs to support pressure-based coupled solver and radiation heat transfer models. HFSS and HFSS SBR+ use GPUs to support various frequency and time-domain electromagnetic analyses. EMIT specializes in radiofrequency interference for complex environments. DesignerSI tests signal integrity and electromagnetic interference analysis. Maxwell is for 2D and 3D low-frequency electromagnetic and electromechanical analysis. For licensing, Ansys generally treats each GPU in a workstation or high-performance computing cluster the same as a single-core CPU.

Ansys continues to invest in GPUs.

"Our customers can cut the time for typical Ansys Mechanical models in half, enabling them to innovate products faster across the entire life cycle," says Wim Slagter, Ansys director of HPC and cloud marketing.

In a performance test with Fluent, Ansys compared use of a four-core CPU workstation with a 32-core CPU workstation equipped with two Quadro GV100 GPUs. The CPU/ GPU combo outperformed the CPU-only workstation by a factor of 5.5x.

GPUs in Other Applications

The following offers examples of how GPUs are becoming more common as a co-computing platform with the CPU.

Altair uses GPUs to improve a wide range of simulation

ENGINEERING COMPUTING III CPU & GPU

and analysis functions across its portfolio.

"Multiple physics can be accurately simulated on GPUs," notes an Altair brief, "to explore and evaluate alternatives overnight and significantly speed up design workflows." The company says advanced monitoring and predictive maintenance simulations can run up to six times faster using GPUs than on a CPU-based workflow.

Autodesk is adding GPU acceleration to many of its products. VRED 2021 now does ray tracing on the GPU instead of in the CPU. In a test comparing CPU and GPU ray tracing, a dual-CPU workstation with 40 CPU cores was compared to one, two and three NVIDIA RTX 8000 GPUs. One GPU was 2.3x faster than the CPU-only workstation; the three-GPU workstation was 6.6x faster. The latest releases of Alias, Arnold and Fusion 360 also include GPU-specific upgrades.

Creaform offers various 3D measurement solutions used in metrology and other engineering fields. Their HandySCAN 3D, Go!SCAN 3D and MetraSCAN products require an NVIDIA Quadro RTX5000 GPU running OpenGL 4.5 or higher.

Dyndrite is a software startup creating the first GPUaccelerated geometry kernel, the Accelerated Computation Engine. The software simultaneously supports various geometry types including surface meshes, B-reps, volumetric data, voxels and tetrahedral meshes.

Granuleworks also develops DEM software and specializes in powder simulations. The software is optimized for the Volta and later generation of NVIDIA GPUs. With a 16-core Intel Xeon workstation CPU as the 1.0 score in a benchmark, a GPU-equipped workstation scored a 22.48x faster resolution time for a ribbon mixer simulation.

Hexagon MSC Actran offers GPU acceleration in its 2021 suite of noise, vibration and harshness simulation applications. The updated multifrontal massively parallel solver, for example, uses GPU acceleration to perform 10x faster than previous versions.

Numeca specializes in turbomachinery simulation. OMNIS Turbo can scale linearly on either thousands of CPU cores or on multiple GPUs. Numeca says GPU-based simulations generally run 2.4x faster than CPU-only runs.

PTC Creo is a multi-app CAD platform. The core de-

sign environment, Creo Parametric, can work with either NVIDIA or AMD GPUs to enhance various performance aspects. Full-screen anti-aliasing in real time allows designers to work with smooth, accurate edges. Creo Simulation Live, an adaptation of Ansys Discovery Live for Creo, requires an NVIDIA GPU from the Kepler, Maxwell or Pascal product generations.

Rocky ESSS is a specialist in particle physics, also known as discrete element modeling (DEM). The solver in Rocky 4 can distribute a simulation across multiple GPUs. A commercial-scale high-shear wet granulation simulation that used multiple GPUs was able to simulate more than 10 million particles for the first time in company history. "These kinds of very high particle counts were not possible previously but are now a reality," the company says.

Turbostream CFD optimizes for CPU and GPU use. A study at the U.K.'s University of Cambridge performed a "typical, routine" Deverson simulation using 3 million grid nodes. The simulation took 8 hours to run on a four-core CPU and 20 minutes to run using a GPU. DE

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→ MORE INFO

AMD: AMD.com

Ansys: Ansys.com

• Dell: Dell.com

• Luxion: Luxion.com

NVIDIA: NVIDIA.com

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PROTOTYPE & MANUFACTURE || 3D Printing

Powering Up

Eaton embraces additive manufacturing in a big way.

BY KIP HANSON

hen Joseph Eaton left his position at Republic Motor Truck in 1919 to form the Eaton Axle Co., he likely didn't imagine what his fledgling company would look like 100 years later. Originally a manufacturer of gear-driven truck axles, Eaton has since become a global supplier of electrical, hydraulic and mechanical power management solutions. The company now employs 97K employees, boasts revenues of \$21.4 billion annually and sells its products to customers in more than 175 countries.



He also couldn't have fathomed how Eaton's products are made. Granted, he and his contemporaries would at least recognize modern computer numerical control machinery, but building parts one paper-thin layer at a time from metal or polymer powders? Impossible. And yet, that's precisely what employees at one pioneering Eaton facility began doing in 2013.

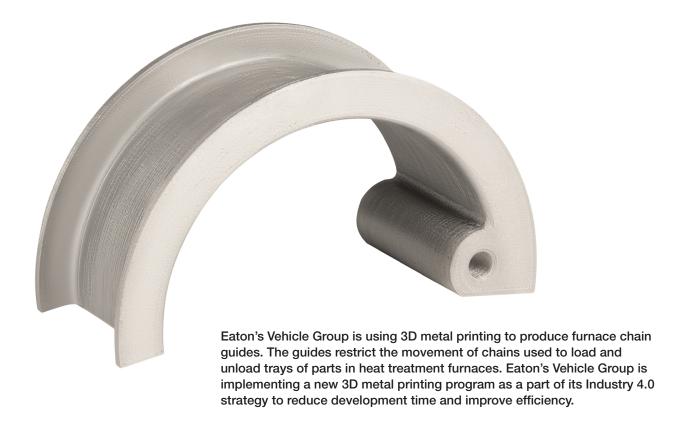
Thanks in large part to the efforts of Eaton's Vehicle Group team, the company now has dozens of 3D printers, with more on the horizon. Possibly lots more.

Embracing the Future

"In early 2018, our group decided to put significant focus on Industry 4.0, and 3D printing falls under that umbrella," says Alexandre Georgetti, director for manufacturing strategy for Eaton's Vehicle Group in Kalamazoo, MI. "So as of right now, we have polymer printing capabilities in 25 of our manufacturing sites, spread across Brazil, Mexico, the United States, Europe, India, China and South Korea."

Eaton's Vehicle Group also has regionally deployed metal printers, with four machines installed so far, and is currently evaluating binder jet technology for pro-

duction purposes. Georgetti noted that diversifying like this increases flexibility, in that one site might come up with a useful product design that can then be deployed immediately wherever it's needed.



"They can just grab the model off the server and print it," he says.

The parts produced with these machines depend mainly on their function and strength requirements. Georgetti is not able to name any 3D printer brands or specific technologies, but says most of what they print falls into the tooling category. This includes jigs and fixtures, quality and safety devices, robotic grippers and production floor aids.

One notable example of an aid for the production floor is a 3D-printed metal oil fill nozzle to streamline differential

assembly. Somewhat surprisingly, only 10% or so of the time is spent printing prototypes, although that may change based on current development needs.

Material Wealth

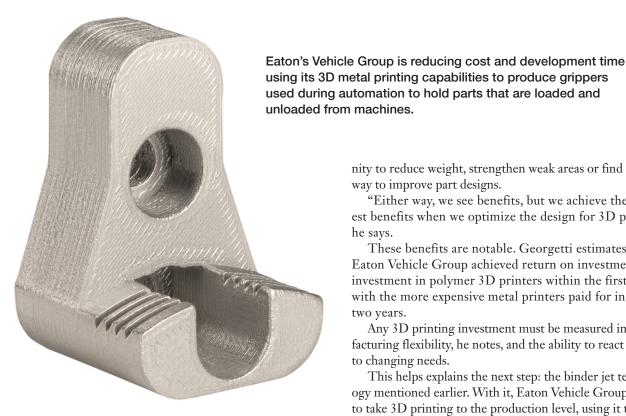
As for what those parts are made of, the Eaton Vehicle Group relies on three primary materials within each printer category. On the polymer side, there's ABS, PA12 (a type of nylon) and thermoplastic polyurethane (TPU), while metals are largely confined to 17-4 PH stainless, 4140 alloy and

> H13 tool steel, with this latter group often being heat-treated post-machining for greater hardness or strength.

> "TPU is a really nice material in applications where there's shock involved, such as hand tools and that sort of thing," Georgetti adds. "It's quite flexible but very hard to break. But there are also situations where we'll combine metal and polymer within the same device. For instance, we might create polymer wear components that can be printed and replaced, rather than replacing the entire unit. This saves a great

> Eaton's Vehicle Group is creating assemblybearing press tools using 3D metal printing. These assembly devices are used to press bearing tapper cones to a shaft during assembly operations.

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deal of money and reduces downtime."

Printing replacement parts is another common task. In this task and other reverse engineering-related activities, the workpiece must often be 3D scanned before printing. This is because drawings are often not available, either because it's part of a purchased assembly, or the product has reached obsolescence and replacement parts are no longer made. Whatever the case, a technician will use a blue light scanner accurate to "around 35 microns" to create a solid model, which can then imported directly to the build software of whatever 3D printer has been tasked with reproducing the component.

Designing for Additive

However, there's often an interim step: making the part more functional, more 3D printable or both.

"Sometimes you can just scan the part, keeping the legacy design, and it will work perfectly fine as is," says Georgetti. "Other times, though, the software will raise a flag. There might be a wall that's too thick for easy printability, for example, or an overhang that requires build supports, and a human will have to intervene."

In these instances, he explains, designers have an opportu-

nity to reduce weight, strengthen weak areas or find another way to improve part designs.

"Either way, we see benefits, but we achieve the greatest benefits when we optimize the design for 3D printing," he says.

These benefits are notable. Georgetti estimates that the Eaton Vehicle Group achieved return on investment on its investment in polymer 3D printers within the first year, with the more expensive metal printers paid for in roughly two years.

Any 3D printing investment must be measured in manufacturing flexibility, he notes, and the ability to react quickly to changing needs.

This helps explains the next step: the binder jet technology mentioned earlier. With it, Eaton Vehicle Group hopes to take 3D printing to the production level, using it to manufacture end-use components for use in customer products

"Our idea is to use binder jet for high-mix, low-volume parts," Georgetti says. "We are planning to start in the aftermarket business, but as the technology matures and our experience increases, there's really no limitation as to how far we can take it." DE

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

MORE INFO

 Eaton Vehicle Group: Eaton.com/Eaton/ProductsServices/ Vehicle/index.htm

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ENGINEERING COMPUTING || Workstations

Superlaptop Falls Short:

Breaking Down Eurocom Nightsky **ARX15 Mobile Workstation**

The company's new Nightsky is fast, loud and expensive.

BY DAVID COHN

anadian system integrator Eurocom has always impressed us with its ability to deliver some powerful mobile computers. The company's Tornado F5W, which we reviewed not long ago (DE, April 2019; bit. ly/2Z9fsz0) blew us away, delivering some of the fastest performance we have ever recorded for a laptop.



Fig. 1: The Eurocom Nightsky ARX15 may be fast, but it is also loud, has terrible battery life and may be incompatible with features of some MCAD software. Image courtesy of David Cohn.

We were quite excited when we received their newest mobile system: the Eurocom Nightsky ARX15. Billed as "the world's first super laptop powered by an AMD Ryzen 3000 series desktop processor in a laptop form," we expected great performance yet anticipated the use of desktop components would lead to reduced battery life. But it was not that simple.

Eurocom actually sells two versions of the Nightsky: the RX15 (equipped with an Intel CPU) and the ARX15 (based on the AMD Ryzen 9 processor). Because we received an ARX15, it meant that we would be testing our first AMD Ryzen-based mobile system.

With an advertised starting price of \$1,999, we hoped that the Nightsky ARX15 would be one of the more affordable Ryzen-based systems, but that starting price proved a bit misleading.

The base configuration includes an AMD Ryzen 7 3700X 8-core 3.6GHz CPU, 16GB of 2666Mhz memory, an NVIDIA GeForce RTX 2070 graphics board and a 1TB SATA3 hard drive. The \$1,999 price tag does not include an operating system and comes with only a one-year warranty.

The Eurocom Nightsky ARX15 supports up to 64GB of RAM and up to 24TB of storage with two M.2 drives plus a mechanical drive. The system we received included multiple upgrades that drove the total cost into the stratosphere.

The Eurocom Nightsky ARX15 comes housed in a sculpted charcoal gray case, which measured 14.25x10.25x1.5 inches and weighed 5.82 lbs., plus an additional 1.83 lbs. for its 230-watt power supply (6.06x2.88x1.18 in.). Raising the lid revealed the 15.6-in. display as well as a 103-key backlit keyboard and numeric keypad.

You can choose among 15 keyboard backlight colors,

Mobile Workstations Compared	Eurocom Nightsky ARX 15 15.6-in. mobile workstation (3.5GHz AMD Ryzen 9 3950X 16-core CPU, NVIDIA GeForce RTX 2070, 64GB RAM, 2x 4TB NVMe PCIe SSD)	Lenovo ThinkPad P1 Gen 3 15.6-in. mobile workstation (2.7GHz Intel Core i7-10850H 6-core CPU, NVIDIA Quadro T2000, 32GB RAM, 1TB NVMe PCle SSD)	MSI WS66 10TMT 15.6-in. mobile workstation (2.4GHz Intel Core i9-10980HK 8-core CPU, NVIDIA Quadro RTX 5000, 64GB RAM, 1TB NVMe PCIe SSD)	Dell Precision 5750 17.3-in. mobile workstation (2.40GHz Intel Xeon W-10885M 8-core CPU, NVIDIA Quadro RTX 3000 w/Max-Q Design 32GB RAM, 1TB NVMe PCIe SSD)	Dell Precision 5550 15.6-in. mobile workstation (2.30GHz Intel Core i7-10875H 8-core CPU, NVIDIA Quadro T2000, 32GB RAM, 1TB NVMe PCIe SSD)	Lenovo ThinkPad P1 G2 OLED 15.6-in. mobile workstation (2.80GHz Intel Xeon E-2276M 6-core CPU, NVIDIA Quadro T2000, 32GB RAM, 1TB NVMe PCIe SSD)
Price as tested	\$8,512.00	\$2,795	\$3,999.00	\$5,219	\$4,355	\$3,133
Date tested	9/2/2020	11/2/20	10/1/20	8/28/20	6/24/20	2/16/20
Operating System	Windows 10 Pro 64	Windows 10 Pro 64	Windows 10 Pro 64	Windows 10 Pro 64	Windows 10 Pro 64	Windows 10 Pro 64
SPECviewperf 13.0 (higher is better)	11001	11001		11001		1.001
3dsmax-06	183.08	84.10	174.60	132.73	91.74	76.32
catia-05	109.70	140.38	256.00	173.75	147.96	126.46
creo-02	178.81	113.82	233.21	159.58	116.59	101.20
energy-02	19.94	17.60	40.50	29.78	17.31	17.11
maya-05	249.96	115.32	228.70	153.66	112.25	102.12
medical-02	53.19	50.96	103.67	73.08	51.11	47.95
showcase-02	101.02	44.65	95.62	74.54	43.99	36.50
snx-03	15.25	147.97	291.91	189.01	144.50	191.81
sw-04	87.13	105.23	156.49	110.18	100.81	86.57
SPECapc SolidWorks 2015 (higher is better)	21112					
Graphics Composite	n/a	2.82	5.43	3.82	3.43	2.81
Shaded Graphics Sub-Composite	n/a	1.43	3.36	1.94	1.77	1.41
Shaded w/Edges Graphics Sub-Composite	n/a	2.04	4.25	2.88	2.67	2.03
Shaded using RealView Sub-Composite	n/a	1.92	3.92	2.62	2.42	1.91
Shaded w/Edges using RealView Sub-Composite	n/a	2.54	4.69	3.47	3.28	2.60
Shaded using RealView and Shadows Sub-Composite	n/a	2.21	4.49	3.04	2.85	2.23
Shaded with Edges using RealView and Shadows Graphics Sub-Composite	n/a	2.70	4.94	3.67	3.45	2.76
Shaded using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	n/a	7.35	15.06	9.86	7.51	6.92
Shaded with Edges using RealView and Shadows and Ambient Occlusion Graphics Sub-Composite	n/a	7.82	14.68	10.68	8.64	7.79
Wireframe Graphics Sub-Composite	n/a	3.08	4.08	3.85	3.53	3.13
CPU Composite	n/a	3.45	7.13	3.55	3.09	3.19
SPEC Workstation v3 (higher is better)						
Media and Entertainment	3.43	1.72	2.33	2.20	1.93	1.63
Product Development	1.56	1.80	2.38	2.29	2.09	1.62
Life Sciences	2.91	1.52	2.35	2.15	1.59	1.54
Financial Services	4.72	1.31	1.76	2.13	1.54	1.53
Energy	2.33	1.02	1.50	1.43	1.30	0.99
General Operations	2.15	1.96	2.07	1.92	1.96	1.90
GPU Compute	3.77	1.85	3.61	3.09	1.91	1.79
Time	07 :	40 ==	00 ==	05	05 -	40.77
AutoCAD Render Test (in seconds, lower is better)	27.1	43.70	28.70	35.60	38.9	49.00
Battery Life (in hours:minutes, higher is better)	55.0	7:04	9:50	10:30	10:22	7:14

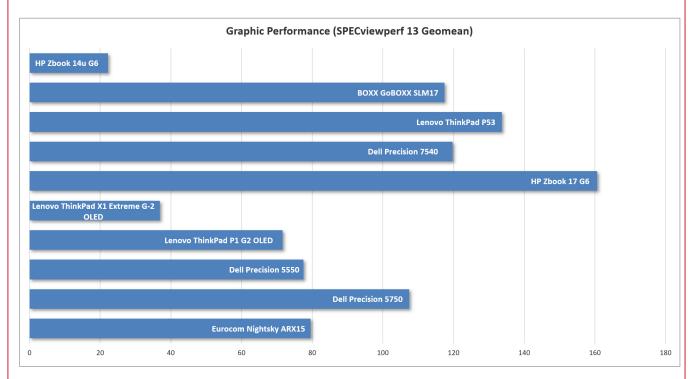


Fig. 2: Graphic performance of recent mobile workstations, based on the SPECviewperf 13 geomean results.

and the standard keyboard is a U.S. English language version. Keyboards for other languages including U.K. English, French, German and Spanish cost \$83 more. The keyboard had a decent feel but was marred by a frustrating layout. For example, the small left-shift key caused us to frequently press the adjacent backslash key instead.

A 4.25x2.5-in. gesture-enabled touchpad with a pair of buttons and fingerprint reader are centered below the spacebar. Centered above the display is a 1-megapixel webcam and microphone array. There are also a pair of speakers for the integrated SoundBlaster audio.

A small power button is located in the upper-right corner above the numeric keypad and illuminates when the system

is powered up, but none of the other keys have LEDs. Instead, an indicator appears briefly on the screen when you enable caps lock and number lock.

Lots of Options

The right side of the case provides a single USB 2.0 port, a 2-in-1 audio jack (headphone and microphone) as well as a separate microphone-in jack, and a large exhaust air vent. The left side houses a security lock slot, an RJ-45 network connector, two USB 3.2 Gen 2 Type-A ports and a MicroSD card reader. The rear panel includes a USB 3.2 Type-C port that also supports DisplayPort 1.4, an HDMI port, a mini Display-Port, a power connector and two large air intake vents.

Eurocom Responds

he Eurocom Nightsky ARX15 is designed to be a very high-performance mobile system. To achieve this, the computer uses some components originally designed for desktop rather than laptop systems. Their higher power consumption requires significant additional cooling, which results in higher fan noise. Eurocom has recently updated the BIOS to address this. Users can control fan speed. Slowing the fan to reduce noise will reduce performance while also improving battery life. But the battery in this system is meant more as a UPS than as a way to power the system for long periods of time. As for the system being unable to complete some tests, several of the

benchmarks used by DE can only be run on systems equipped with NVIDIA Quadro graphics boards, so the Nightsky ARX15 is unable to run those tests, but is otherwise compatible with most software. Lastly, we included two 4TB M.2 drives to demonstrate that Eurocom is unique in being able to include up to 16TB of solid-state storage in our mobile systems. We are also working with vendors to enable future mobile systems to include 128GB of system memory.

Editor's response: The benchmarks used by DE do not require NVIDIA Quadro graphics boards and can typically be run on systems equipped with other GPUs.

ENGINEERING COMPUTING || Workstations

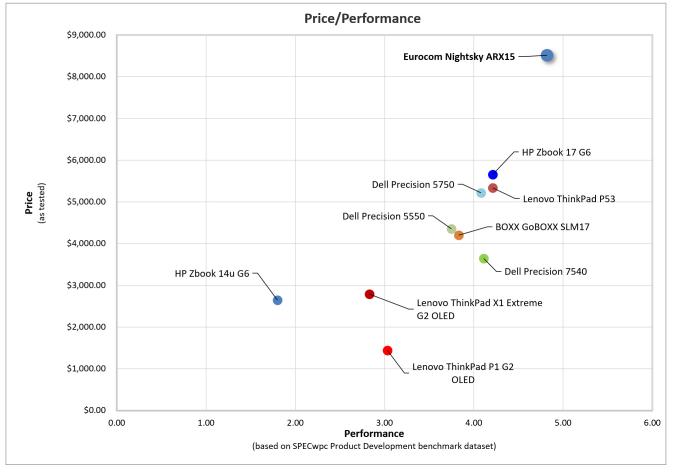


Fig. 3: Price/Performance chart based on SPECwpc Product Development benchmark dataset.

There are also more air vents on the bottom of the case as well as a removable panel to access the internal battery. The entire bottom panel also can be removed to access the hard drive, memory and other internal devices, but a big red warning in the manual cautions that doing so may violate the warranty terms. Four LEDs along the front edge of the system indicate power, battery status, Wi-Fi and hard drive activity.

In addition to the Ryzen 7 3700X in the base configuration, Eurocom offers a choice of three other 3000 series Ryzen processors: the Ryzen 7 3800X 8-core 3.9GHz, the Ryzen 9 3900X 12-core 3.8GHz and the AMD Ryzen 9 3950X that was provided in our evaluation unit. This 3.5GHz CPU (4.7GHz max turbo) includes 16 cores, but consumes 105 watts and adds \$667 to the total cost.

Although the base unit comes with 16GB of memory using a single small-outline dual-inline memory module (SO-DIMM), the Nightsky ARX15 can accommodate up to 64GB of RAM, using two 32GB SODIMMs. Again, Eurocom offers an array of memory configurations. Our evaluation unit came with 64GB of memory, using two Micron/Crucial DDR4-3200MHz SODIMMs, which added \$1,292.

Though our system included the base configuration NVIDIA GeForce RTX 2070 discrete graphics card, you can

actually downgrade to a GeForce RTX 2060 to save \$194. The RTX 2070, based on NVIDIA's Turing architecture, includes 8GB of GDDR6 memory and 2560 compute unified device architecture cores. Its 256-bit interface delivers a bandwidth of 448 GB/seconds, but the board consumes 215 watts. This graphics processing unit (GPU) powers a 15.6-in. 144Hz 1920x1080 in-plane switching (IPS) panel capable of displaying 98% of the sRGB gamut and is the only panel offered.

As previously mentioned, the base configuration includes a 1TB SATA drive, but as we have come to expect from Eurocom, that is just the starting point. Though mechanical drives of up to 8TB are available, our system eliminated the mechanical drive entirely (saving \$89) and instead contained a pair of solid-state drives (SSDs).

Eurocom offers nine different M.2 SSDs, ranging from a 250GB Samsung drive to an 8TB SSD, and the Nightsky ARX15 supports RAID 0 or 1 on systems equipped with two identical drives. For our evaluation unit, Eurocom went over the top, including two 4TB Sabrent Rocket M.2 non-volatile memory express drives. At \$2,083 each, they added \$4,166 to the total cost, but the expense hardly seems justified.

Our system included the Intel AX200 wireless LAN module with 802.11AX and Bluetooth that comes standard,

although you can upgrade or downgrade this option.

With so many power-hungry components, the removable 6-cell 62Whr lithium ion battery can only be considered to be an uninterruptible power supply (UPS), and powered the system for less than 55 minutes before shutting down, which makes it the worst battery life of any laptop we have ever tested.

Although the system remained relatively cool, reaching a peak of only 109°F, the Eurocom Nightsky ARX15 was exceptionally loud, hitting a peak of 70dB under heavy compute loads (equivalent to a vacuum cleaner), and averaged a very noticeable 55dB even at idle.

Good, Bad and Ugly

With its fast 12-core CPU and high-end GPU, we expected the Eurocom Nightsky ARX15 to deliver great performance—and on many of our tests it did. But on the SPECviewperf test, which measures pure graphics performance, the Eurocom Nightsky ARX15 was a mixed bag, turning in the top score on one dataset but lagging recently tested systems on others.

The situation became more troubling when we tried to run the SPECapc SolidWorks test. Because the NVIDIA Ge-Force RTX 2070 graphics card does not support the Solid-Works RealView feature, which is an integral part of this test, we could not even run this benchmark. We experienced this same issue when we tested the Lenovo ThinkPad X1 Extreme G1 (*DE*, July/August 2020; bit.ly/373thTT).

On our AutoCAD rendering test, the 27.1-second average time was nearly 8 seconds faster than the fastest mobile workstation we have ever tested, a truly amazing result. And on the latest versions of the very demanding SPECwpc workstation performance benchmark, the Eurocom Nightsky ARX15 turned in the best results we have ever recorded on six of the seven use cases.

But the one it did not win, Product Development, is the one of most interest to *DE* readers, and on this test, it finished behind eight of the 10 mobile workstations we have most recently tested. We base our price/performance chart on the older SPECwpc v2.0 test, and on this benchmark, the Eurocom Nightsky ARX15 turned in top marks on the Product Development portion of the test.

Though its high-end Ryzen processor and 64GB of RAM doubled the system cost, that would still have only brought the price to \$4,000. The inclusion of not one, but two, 4TB SSDs more than doubled that.

As equipped, including the Windows 10 Professional 64-bit operating system that came pre-installed, our Eurocom Nightsky ARX15 would cost \$8,512, making it the most expensive mobile system we have ever tested. Even substituting a single 1TB M.2 drive for the pair of 4TB drives would still only reduce its cost to \$5,263. Since the base price only included a 1-year return-to-factory depot warranty, our astested price also adds \$313 for a 3-year warranty.

Although there are certainly some users who would spend that much to obtain an extremely fast mobile system, in the case of the Eurocom Nightsky ARX15, we simply cannot justify its purchase. We have recommended systems before that lacked independent software vendor certification, but the Nightsky ARX15 can only be seen as a highend gaming laptop, not a mobile workstation. The Eurocom Nightsky ARX15 may be fast, but it is also loud, suffers from absolutely terrible battery life, has an awkward keyboard and may not be compatible with some software typically used by our readers. **DE**

David Cohn is the senior content manager at 4D Technologies. He also consults and does technical writing from his home in Bellingham, WA and has been benchmarking PCs since 1984. He is a Contributing Editor to Digital Engineering and the author of more than a dozen books. You can contact him via email at david@dscohn.com or visit his website at www.dscohn.com.

→ MORE INFO

• Eurocom: <u>Eurocom.com</u> Eurocom Nightsky ARX15

Price: \$8,512 as tested (\$1,999 base price) **Size:** 14.25x10.25x1.5-in. (WxHxD) notebook

Weight: 5.82 lbs. plus 1.83-lb. 230-watt power supply

CPU: 16-core 3.5GHz AMD Ryzen 9 3950X w/64MB L3 cache

Memory: 64GB DDR4 at 3200MHz

Graphics: NVIDIA GeForce RTX 2070 w/8GB GDDR6 memory

LCD: 15.6-in. 2K 1920x1080 IPS, anti-reflective

Camera: 1megapixel webcam

Hard Disk: Two 4GB Sabrent Rocket M.2 NVMe SSD

Audio: SoundBlaster Cinema 6 with built-in speakers and microphone and two audio jacks (microphone/headphone and microphone-in)

Network: Intel AX200 Wi-Fi 6 802.11AX plus Bluetooth

Ports: One USB 2.0, two USB 3.2 Gen 2 Type-A, one USB 3.2 Type-C with DisplayPort 1.4, HDMI, mini DisplayPort and RJ-45

Other: MicroSD card reader, fingerprint sensor

Keyboard: Integrated 103-key backlit keyboard

Pointing device: Integrated touchpad with two buttons

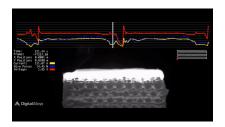
OS: Windows 10 Professional 64-bit

Warranty: 1-year return to factory depot (3-year warranty included in as-tested price)

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



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



Real-time Quality Assurance for Metal Additive

New module is Data Analyzer, software for quality assurance and data analysis.

Digital Alloys has released a software module for its Joule Printing process control software, Foundry. It's called Data Analyzer, software for quality assurance and data analysis. Together with existing Foundry modules, Data Analyzer offers nondestructive inspection of printed parts. The result is a capability for quality control in a Joule Printing factory. The company says Joule Printing is "an order of magnitude higher print resolution" compared to Wire Directed Energy Deposition.

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Special Composite Material for Electronics AM

Material can be reinforced with continuous carbon fiber, creating static-free parts.

Markforged introduces Onyx ESD, a new composite material for additive manufacturing of electronics. Electronics manufacturers must use materials that meet electrostatic discharge (ESD) safety requirements, to avoid damaging a product or component during production. Though other ESD-safe materials are on the market, Markforged's offers a high strength (when paired with continuous carbon fiber), tight surface resistance range and smooth surface finish.

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UL Certification for Emissions-free 3D Printing

RIZE calls GREENGUARD Certification "a key safety and sustainability milestone."

RIZE has been awarded GREENGUARD Certification from Underwriters Laboratories for a set of materials for fused deposition modeling (FDM). For now the certified materials only work on the RIZE 2XC FDM 3D printer, but other FDM manufacturers may be able to fine-tune their printers to use these new emissionsfree materials. The RIZIUM material portfolio from RIZE includes composite materials for strong, durable parts and release material.

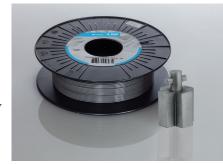
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Debuting Filament-based Stainless Steel for AM

New filament comprised of metal powder with a polymer binder.

Forward AM, subsidiary of BASF, introduces the latest in its line of fused filament fabrication (FFF) 3D printing materials. Ultrafuse 17-4PH is a filament made of metal powder with a polymer binder. After debinding and sintering, the final 3D printed part is 17-4 stainless steel. Forward AM says Ultrafuse 17-4PH can be fully heat treated to high levels of strength and hardness. This makes it ideal for petrochemical, aerospace, automotive and medical manufacturing.

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Achieve Faster Production Drawings From 3D Model

There are various user interface improvements, including easier access to catalogs.

IronCAD introduces IronCAD 2021, aiming to improve the process of generating 2D production drawings from the 3D model. The company says every year it polls its users about enhancements they'd like to see in the software. For 2021 the clear response was to improve productivity when generating production (shop) drawings from an IronCAD 3D model. To that end IronCAD 2021 offers several new features and improvements specific to the production drawing process.

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Transition to AM for Improved Part Performance

3D Systems group is consultancy package of application engineering resources.

3D Systems introduces its Application Innovation Group, consulting and manufacturing resources and services for the optimization of fluid flow part designs. The group offers engineering and manufacturing services including AM parts manufacturing on demand in ISO 13485 and EN/AS9011 certified facilities; training to help companies integrate design for additive manufacturing and portfolio screening into operations; and technology transfer services for projects at any stage.

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Simulation Software Tackles Sintering in AM

Software may enable use of binder jet sintering on challenging geometries.

Live Sinter from Desktop Metal is a new sintering process simulation software that corrects for shrinkage and distortion of binder jet 3D printing parts during sintering. Desktop Metal says Live Sinter results in near-net shape parts after sintering, achieving tight shape and dimensional tolerances while diminishing or eliminating the need for sintering supports. Additive manufacturing engineers now have a software option for testing fast and predictable sintering outcomes.

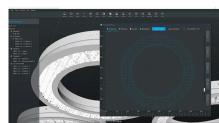
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Software Made for Fast AM Build Prep

HP Universal Build Manager powered by Dyndrite is an OEM, process-agnostic tool.

HP has teamed up with start-up software developer Dyndrite to create HP Universal Build Manager Powered by Dyndrite (UBM), which it describes as "a robust solution" for delivering CAD-to-print workflows for additive manufacturing. The tool offers software tools for build preparation, CAD import, patterning, nesting, labeling, support generation and slicing. The Dyndrite engine supports NVIDIA Enterprise GPUs for computational acceleration.

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Next-Gen Engineers

Student Competition Profile: SAE AutoDrive

Academia Plugs in to Autonomous Technologies

BY JIM ROMEO

AE International and General Motors have partnered to headline sponsor AutoDrive Challenge, the latest of SAE International's Collegiate Design Series. This newly established, four-year autonomous vehicle competition tasks eight university student teams to develop and demonstrate a full autonomous driving passenger vehicle.

Allison Hostetler is the director of pre-professional education at SAE International. We spoke to Allison to get a better understanding of their competition.

Digital Engineering: Can you provide an overview of the AutoDrive Challenge competition, how it came to be and the intent of the program? Who will be participating or who has participated? How many participants have you had or are you expecting? Any demographics of participants?

Allison Hostetler: The technical goal of the competition is to navigate an urban driving course in an automated driving mode as described by SAE Standard (J3016) Level 4 definition in the fourth year of the competition.

Throughout the AutoDrive Challenge competition cycle, students and faculty will be invited to attend technology-specific workshops to help them in their concept refinement and overall autonomous technical understanding. The competition consists of eight teams from select universities that were invited to participate in the inaugural competition.

Year 1 (2018) focused on the concept selection for the university teams by having them become familiar with



Right, bottom: Each team approached the architecture and dynamic challenges differently.

their sensing and computation software. They were tasked with completion of a concept design written paper as well as simple missions for on-site evaluation in Yuma, AZ.

specific workshops.

Year 2 (2019) focused on urban driving scenarios with static and dynamic objects. Teams will complete these test at Mcity, a one-of-a-kind urban test facility at the University of Michigan that simulates a broad range of complexities that vehicles encounter in urban and suburban driving settings.

Year 4 (2021) is the last year of this inaugural series of the AutoDrive Challenge competition and will challenge the teams to show what the previous three years of development and learning has produced. The teams will face two dynamic challenges in this last year.

One will be a culminating drive that links together all the elements and features experienced in the previous three years. The second will be SAE Standard (J3016) Level 4 proof of concept demonstration drive.

Additionally, teams will be required to generate reports, presentations and perform simulations to highlight their work and communicate what they have learned.

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

Hostetler: The competition focuses on each university team receiving a standard Chevy Bolt EV; [they] are tasked with integrating autonomous sensors and building a software and

Next-Gen Engineers



The SAE AutoDrive Challenge consists of eight teams from select universities that were invited to participate in the inaugural competition.

hardware architecture. Each team uses an Intel Compute Platform to power their autonomous driving along with LIDARs, radars and cameras that make up their sensor suite. Although each team has access to all the components mentioned, each of the eight designs are unique and each team approached their architecture and achieving dynamic challenges differently. Each team was also given simulation software and competed in a MathWorks Simulation Challenge designed to mirror the Mcity landscape for real simulated testing.

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

Hostetler: Year 3 (2020) of the Auto-Drive Challenge Social Responsibility project tasked teams to help SAE bridge the academia gap and develop a standard for autonomous mobility that includes accessibility. Teams were tasked to research, analyze and standardize their best practice autonomous vehicle design that provides a safe and

operationally user-friendly environment for the general public, which includes disabled citizens.

Year 4 (2021) AutoDrive Challenge Social Responsibility is asking teams to help SAE bridge the academia gap and write a 10-15-page white paper for application of their standard from Year 3, that focused on a topic in autonomous mobility that includes accessibility. Teams are tasked to present a white paper to standardize their best practice autonomous vehicle design that provides a safe and operationally user-friendly environment for the general public, which includes disabled citizens.

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

Hostetler: SAE International is excited to expand upon our already strong partnership with General Motors to build the future STEM workforce through the AutoDrive

Challenge. This relationship builds on our success through STEM programs such as Formula SAE and our A World In Motion (Pre-K to 8th Grade) programming, the AutoDrive Challenge launches a new platform to engage industry and academia in working towards a common goal of preparing the brightest young minds for the future of autonomous technologies.

AutoDrive Challenge is another way General Motors is educating and training next generation of automotive engineers and advance the workforce development in automation and automated vehicles. Through the partnership, SAE and GM offer a unique experience for students to work with industry professionals to tackle the next big opportunity facing vehicle technology: autonomous driving. DE

Jim Romeo *is a freelance writer based in* Chesapeake, VA. Send e-mail about this article to de-editors@digitaleng.news.

MORE INFO ->

• AutoDrive Challenge: AutoDriveChallenge.com



COMMENTARY

By Matthew Sloane, Ph.D., and Frank Gagliardi, Ph.D.



Meshing Data Science With Advanced Manufacturing

dvanced manufacturing and its associated technologies, such as the Industrial Internet of Things (IIoT) that encompasses hardware and software, are revolutionizing the manufacturing processes aimed at optimizing product production.

Within this realm, we find representational digitization as the prime mover, and data the fuel for its models, code and automata. As we enter this realm, which some call Industry 4.0, it is overly evident that any advancements in the physical realm are becoming ever more dependent on the digital world.

Additive manufacturing (AM), a subtechnology of the advanced manufacturing realm, exemplifies this dependency. It is inherently dependent on digitization for the modeling and construction of products. Recognizably, it is the vast amount of data produced throughout the build process and during post-build testing that calls for the integration of data science techniques, which hold the keys to efficiently unlock AM's power. The proper and rapid analysis of data leads to greater returns on investment and provide a means to incorporate the mass commercialization of additive technology in traditionally regulated industries.

An AM strategy rooted in extracting information from rigorous data analysis and applying it as knowledge enables design and forms the foundation for robust qualification and certification processes. Such well-structured knowledge is an essential component for producing higher quality-lower cost products and services.

A Methodical Approach to Data Analysis

The cautionary portent here is that engineers and managers alike may be tempted to apply "advanced analytics" immediately in an unstructured effort to learn

quickly about new, data-rich manufacturing processes.

From a sound business perspective, this is ill-advised. It is incumbent that these engineers, managers and leaders develop and follow a structured, methodical approach to data analysis and analytics. This approach must encompass structures and tools that will lead to better decision-making by transforming specific data to actionable knowledge.

Minimally, a four-step process should include: identify the specific problem and requisite data needed to solve it; apply an iterative learning process to gain an understanding of the situation; model the phenomena in consideration; and use gained knowledge to guide their courses of action.

Manufacturing-centric teams must prepare a strategy early on for identifying, preparing and incorporating pertinent data into their AM projects. Too often, teams ignore the importance of a well-planned strategy and seek answers solely from haphazardly conceived data. Prior to starting a project, teams must identify the specific problem they seek to solve, act in a hypothesis-driven manner and drive intensely at collecting and structuring the data necessary to prove or disprove their hypotheses.

Team engineers, data scientists and managers that prioritize this deliberate strategic approach to data creation and data wrangling will reap the benefits of their efforts. It is important that the stakeholders understand that the type and quality of AM data must be transformative, and not merely based on abundance.

With properly structured data in hand, the teams can seek solutions by applying a hypothesis-driven iterative learning process. The iterative (and adaptive) learning process (Fig. 1) initiates with use of thorough descriptive statistics and visual representations.

The data representations set the basis for analysis with inferential statistics and cycles of deduction and induction leading to final hypotheses regarding

Initiate/Adapt Learning Structured Data Hypothesis, H_i i = i + 1Deduction I_i Consequence of H_i

Fig. 1: The Iterative Learning Process. Image courtesy of Matthew Sloane, Ph.D., and Frank Gagliardi, Ph.D.

the manufacturing processes. These hypothesis types will prove to be of paramount importance and foundational for the teams as AM continues to mature and gain a foothold in the advanced manufacturing industry.

Robust hypotheses allow team members to move to transform what was once seemingly disparate data to a whole representation of the AM process. This is essential because the AM process is inherently complex and data-rich. As the team moves to the modeling phase, their continuous improvement goal should be an effort to optimize the model and represent the process in the simplest, most accurate way.

For example, the model may include an array of independent variables in multiple linear regression analyses to account for factors that influence the dependent variable (or outcome of interest).

At some point, the team will certainly understand the trade-off between complexity and cost if they employ additional independent variables that fail to enhance the model significantly. However, complete teams comprised of engineers, data scientists and managers who grasp this concept and holistically model the process with a data and physics mindset will run truly successful AM projects.

A deliberate and structured approach to incorporating data science with AM will yield models that set a realistic expectation for future manufacturing process behavior. Equipped with this knowledge, engineering and manufacturing teams will be able to design and deliver better products faster. With this proposed discipline and rigor in evaluating data, AM technologies may realize their true transformative power. **DE**

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