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December 2018

SPECIAL ISSUE!

TECHNOLOGY OUTLOOK 2019

Technology Survey Results
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Hyperloop Transports
Supersonic Planes
Exoskeletons
AI Beyond the Hype

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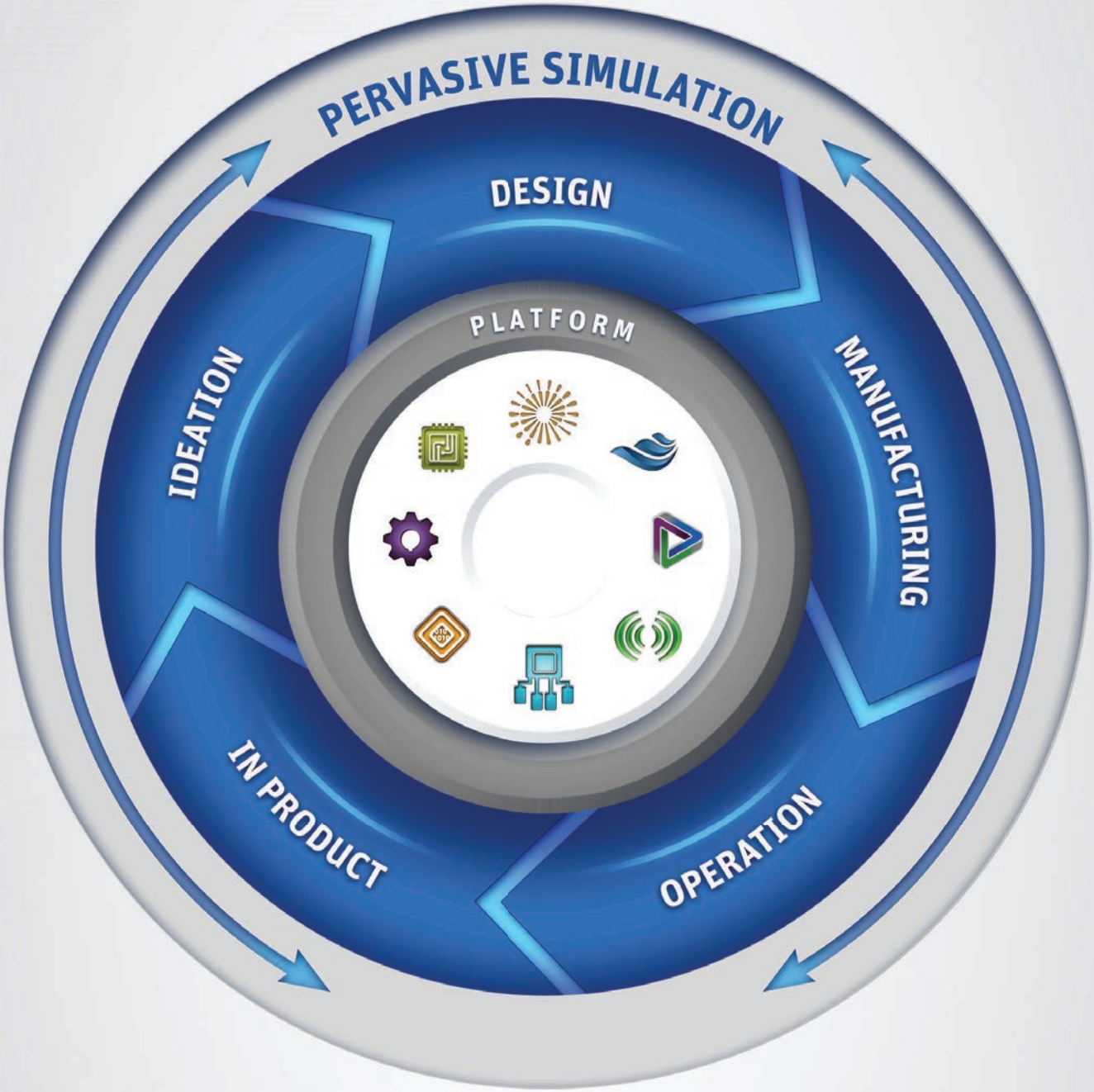

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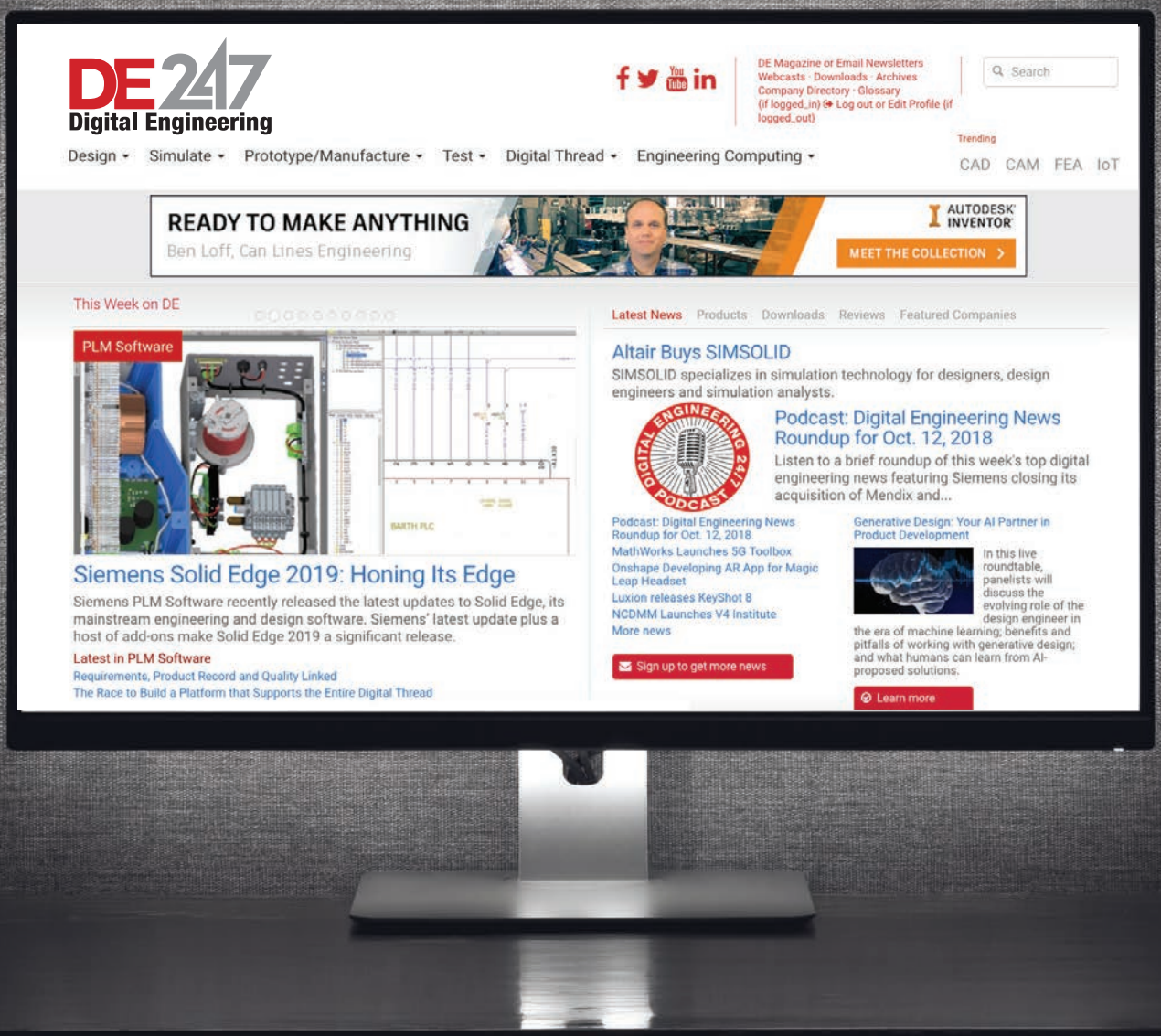

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by Jamie J. Gooch

Keep Moving Forward

ANOTHER YEAR is almost history and we can look forward to advances in a number of foundational technologies that will have far-reaching implications to design engineering.

What those technologies will be is becoming clearer, as 5G mobile networks promising vastly faster wireless speeds are making their public debut, artificial intelligence is being incorporated into more software that is enabled by ever-increasing compute power, while industrial additive manufacturing is beginning to hit its stride—thanks, in part—to increased material development. What the implications of those technologies will be for design engineering is still a matter for debate, but "disruption" is the term most used to describe them (see page 11).

Each year, we survey our audience to get their take on how technological innovations are actually affecting the people on the front lines of designing and engineering new products (see page 8). This year, we decided to also feature some of the design engineering teams at the forefront of creating products that promise to be disruptive: autonomous vehicles, hyperloop projects, supersonic passenger aircraft and exoskeletons.

> **" We should recall that the goal is to make things better for the humans, in spite of all their flaws."**
>
> – *DE* 2018 Survey Respondent

Getting There

There's a reason those articles focus on transportation. Humankind's need to get where we're going faster has a number of side effects—fatal accidents, pollution and lost productivity among them. Electric powertrains, self-driving vehicles and innovation in mass transit may change all that when combined with new business models. For example, some companies have announced their intent to enable autonomous passenger flights, combining the Uber model with advances in electric motor technologies to create what are essentially flying cars.

At the Dassault Systèmes 3DEXPERIENCE Forum in Boston this summer, Joby Aviation's Sean McCluskey shared how the company is using lattice and topology optimization in conjunction with additive manufacturing to help accomplish the company's goal of creating an air taxi service using its electric vertical-takeoff-and-landing (eVTOL) vehicles.

At the 2018 Siemens Industry Analyst Conference in August, Teri Hamlin, VP of Siemens eAircraft USA, shared why the company is using digital twins for every product it makes to address the complexities of electrical propulsion. "By 2050, we think electric propulsion will be the standard," Hamlin said. "We'll see the first FAA certified systems coming toward the end of 2020."

There are more than a dozen companies pushing the autonomous eVTOL aircraft future forward. If flying cars aren't your thing, check out the advances made in hyperloop projects (page 18) and commercial supersonic aircraft (page 22) thanks to simulation, sensors and new materials.

Innovation is moving quickly. For startups to disrupt existing markets and established players to avoid being victims of that disruption, they need design engineering tools and processes to stay ahead. Those looking toward artificial intelligence for such a boost may not find what they expect. AI is so intertwined with sci-fi that its very real benefits in many applications are often met with disappointment that the Singularity hasn't occurred (see page 40).

Don't Lose Sight of the Goal

"Mostly the name is overstated and an oversimplification," wrote one *DE* survey respondent when asked for his impressions of AI. "However the techniques are just starting to be applied. There is huge promise for big data, analytics, AI and cloud services to converge. Predictive failure reports can save huge sums of money while making life more convenient for the end user. We should recall that the goal is to make things better for the humans, in spite of all their flaws."

Making things better requires taking long-term benefits and drawbacks into consideration, such as assisting human workers rather than replacing them (see page 36) or technology's effect on the environment (see page 43). Innovation is moving so quickly that it's easy to lose sight of the purpose of technological advancement. The end goal isn't to disrupt markets. The point is to make the world better. DE

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Dubbed generative design, the new approach often results in shapes and forms that are structurally superior and aesthetically more appealing for the human designers' solutions.

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TECHNOLOGY FOR OPTIMAL ENGINEERING DESIGN

INSIDE

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ON THE COVER:
Images courtesy of Aerion, Hyperloop Transportation Technologies and Ekso Bionics.

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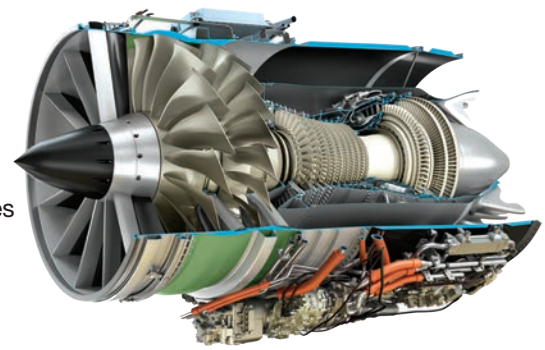

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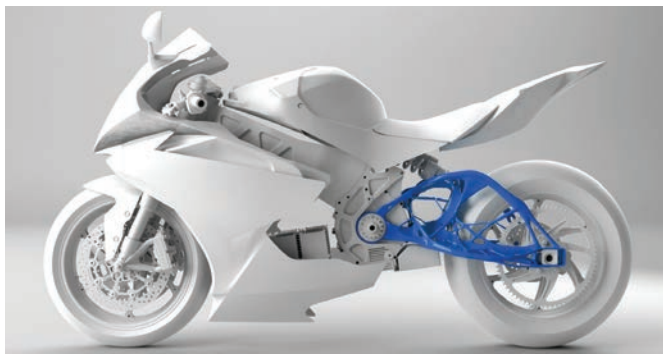

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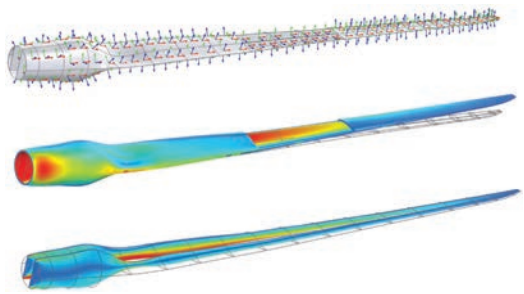

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SIMULATION 101

By Donald Maloy

Part 3: Transition to Simulation Via Training

AT FIRST GLANCE, running simulation studies can be intimidating. You may wonder: Are my results correct? Attempting to learn from tutorials in any software never quite explains in ample detail how to properly run an analysis with confidence. It's only natural to gather resources that will equip you with the right tools to conquer this task. Training courses are a great place to start, but it's essential to know what you are getting up front. Following is the necessary core content for a simulation training course.

If you're a fan of '80s movies, you'll never forget the scene in "Karate Kid" where Mr. Miyagi has Daniel LaRusso learning the wax-on, wax-off routine. This methodology of learning core principles holds true for simulation as well. The entire simulation process can be broken down into three steps: pre-processing, solution and post-processing.

Pre-processing

Every finite element analysis (FEA) initially starts with a completed CAD model. In most instances, much of the detail on the model isn't required for analysis, so removing insignificant geometry reduces solution time. This is commonly referred to as model defeaturing, and it's a good practice to store this version of the file locally with the original. If you plan on using an assembly, the additional step of ensuring that parts don't overlap in space should be addressed as well.

An important aspect that the training should offer is a thorough breakdown of the mathematical model in pre-processing. A mathematical model can be broken down to include the type of analysis, material properties, supports and loads. Each type of analysis or study has limitations on what information is provided in the results and how to set up the mathematical model. For instance, linear static studies, regardless of software, require specific material properties, boundary conditions and geometrically linear behavior to obtain reliable results. Think of this whole process as setting up a physics-free body diagram and assigning materials to the CAD part(s) or assembly.

The Simulation Solution

The most commonly misunderstood portion of running an analysis from a beginner's perspective is the solution step. As the pre-processing is completed, you will break down the CAD model into small finite pieces called elements. This process is often referred to as meshing. Elements vary by specific software companies; however, they are generally broken down by 1-, 2- and 3-dimensional elements. Each has their own specific use and limitation as to where and when they should be used.

Within each element, there will be nodes that have specified degrees of freedom. Degrees of freedom are defined at the nodes as translational, rotational or a mix of both. Assessing the quality of the mesh by reviewing the aspect ratio and quantity of elements in specific regions of the model all play a critical role in providing accurate values in the post-processing step.

Some specific functionality of what is called adaptive meshing may also be available during the solution step. This functionality is where the mesh only refines in required areas to obtain more accurate values and reduces the quantity or quality of elements in areas of less interest. Ideally this allows for reduced solution time and accurate values in areas of stress.

Post-processing

Extracting the correct information from the results and identifying possible errors is the meat and potatoes of any simulation. Organizing the results in such a way that the values are relatable makes everything clearer. This helps you decide whether the analysis was set up correctly.

Depending on specific software, some results extend beyond stress, strain and displacement plots to include Energy Norm Error. For instance, this type of plot will identify the areas of the model where possible stress singularities could exist. Singularities are common artificial errors due to the way the mathematical model was set up and should be identified during post-processing.

You are officially furnished with a basic understanding of what to look for when selecting a simulation course. Components of the training may vary by vendor, but the three-step process holds true for FEA. Once you've conquered the terminology, you'll find that running a successful analysis with the proper training isn't too difficult. The question then becomes: How accurate do I need my results? DE

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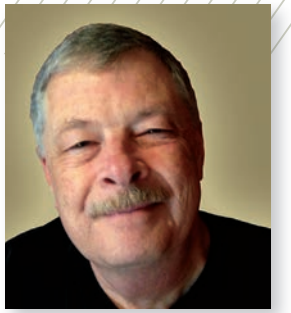
By Tom Kevan



Sensors Boost Robot Performance

FROM WORKING ALONGSIDE humans in pick-and-place operations to material handling in the warehouse, robots are starting to deliver unprecedented levels of performance. But why now? What has changed in the technology's composition that has enabled such a transformation? To a large extent, the answer is the introduction of a multitude of new, innovative sensor technologies.

Numerous factors have converged to position sensing technology as the driving force behind the expansion of robot functionality. For starters, the cost of sensors has steadily declined. Growing use of micro-electro-mechanical systems devices has advanced miniaturization and integration, enabling smaller form factors. Furthermore, sensing devices now boast greater energy efficiency and communications capabilities. All these advantages have proven to be crucial. The heartbeat of robotics' advance, however, lies in sensors' ability to support previously unattainable accuracy and precision.

Distinguishing Between Accuracy and Precision

Users often make the mistake of seeing accuracy and precision as interchangeable. Within the context of robotics, however, the terms have completely different meanings.

Robotics providers define accuracy as the difference between the requested level of performance and the performance actually delivered by the robot. No robot delivers 100% accuracy; there is always a margin of error. As robotics mature and advance, however, the average error rate has dramatically decreased. This is particularly important because a robot's accuracy plays a large part in determining the tasks it can perform.

Developers define precision as a robot's ability to repeatedly perform a programmed task. This is measured by the degree to which a robot can bring its frame or end effector to the same position and orientation over and over again.

Internal and External Sensor Roles

Accuracy and precision affect robot performance in two areas. Internal sensors guide the robot's operation, such as its speed and room orientation or its effectors' positions.

Observe an example of this function in the calibration of a robot's axes. The device's control system must adjust this measurement regularly. Mounted on the robot's axes, the measuring sensors (e.g., a linear variable differential transformer displacement sensor) identify the zero point while the axis is being rotated. Without a high level of accuracy here, the robot can only perform simple tasks.

External sensors provide data on the robot's operating environment. This can involve camera systems, temperature sensors to detect the presence of human co-workers and laser triangulation sensors to determining micrometer-precise distances to—and positions of—tools and the production goods. Many of these applications depend on sensors to provide the accurate, high-speed measurements required by advanced functions.

Additionally, the introduction of sensor fusion has enabled even greater accuracy and precision. This technology combines sensory data from multiple disparate sources, providing a more in-depth picture of the parameter of interest than can be determined by individual sensors.

Giving Robots the Sense of Touch

Robot makers are now adding sensor technologies to their designs that enable robots to more accurately sense their work environments and to more precisely perform tasks. These technologies include force torque sensors and tactile sensors.

Force torque sensors help give robots a sense of touch, allowing them to manipulate objects in less-structured environments with more precision, accuracy and flexibility. Instead of simply following a predefined path, robots with force sensing can adjust to real-world variables and sense when a part is complete or in place.

Tactile sensors impart robots with the precision to delicately manipulate physical objects. An application in which these sensors excel is called piston stuffing—the process of inserting a piston into an engine block. In most cases, the gap around the piston measures less than $^{1}/_{10}$ the thickness of a human hair. Vision systems aren't precise enough to ensure the accuracy of piston stuffing. Only tactile sensors achieve this level of performance, providing a major productivity boost for automotive manufacturers.

The new sensor technologies deliver greater accuracy and precision. These improvements enhance robot productivity, enable a new class of applications and lay the groundwork for the next generation of robots. DE

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

Hope, Hype and Reality

DE readers provide their take on the future of design engineering technology.

BY JAMIE J. GOOCH

THE HEADLINES today read like issues of *Popular Mechanics* from the 1950s: "Self-Flying Aircraft Are Coming Before Autonomous-Driving Cars," "Artificial Intelligence Can Help Fight Global Hunger," "Faster Speeds and Holograms: What to Expect from the New 5G Network," "A New Supercomputer Is the World's Fastest Brain-Mimicking Machine." The future is bright—or dark, depending on your perspective—thanks to innovations in technology.

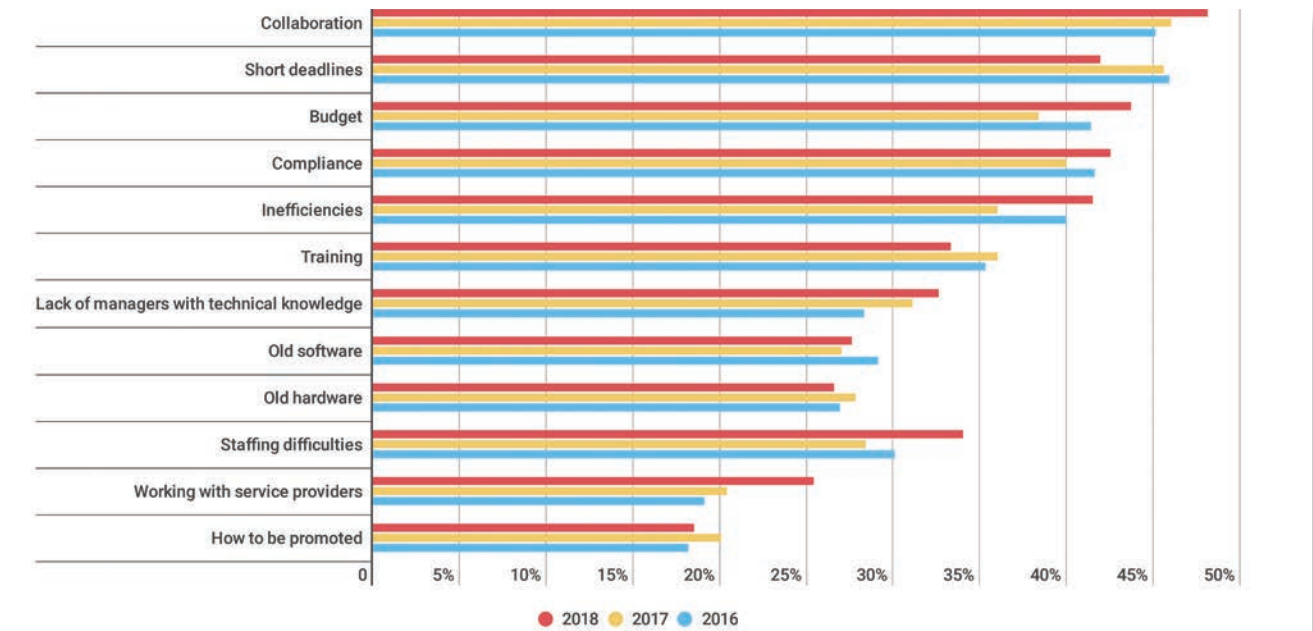
We asked *Digital Engineering's* audience for their perspectives on the current and future technologies shaping design engineering, and thus the products and systems that will comprise our future. Almost 450 people responded, mostly product or system design engineers (33%), followed by engineering management (15%), those involved in research and development (10%) and engineering consulting (9%). The final third identified their primary areas of responsibility as corporate management, engineering analysis, industrial design, IT management, test and measurement, and faculty or students.

Collaboration Continues to be Top Challenge

For the second year in a row, more survey respondents chose collaboration as an extremely/somewhat important challenge in their day-to-day work than other common challenges, including tight deadlines and budgets, regulatory compliance or staffing concerns. Almost half (48%) of respondents chose collaboration this year, slightly more than in 2017 (46%) and 2016 (45%). Perhaps that's not surprising, given the complexity of today's products and systems that combine mechanical and electronic hardware with increasingly sophisticated software, but because the much ballyhooed idea of a digital thread connecting people, machines and processes leans heavily on collaboration, we included the digital thread and digital twins in our survey this year.

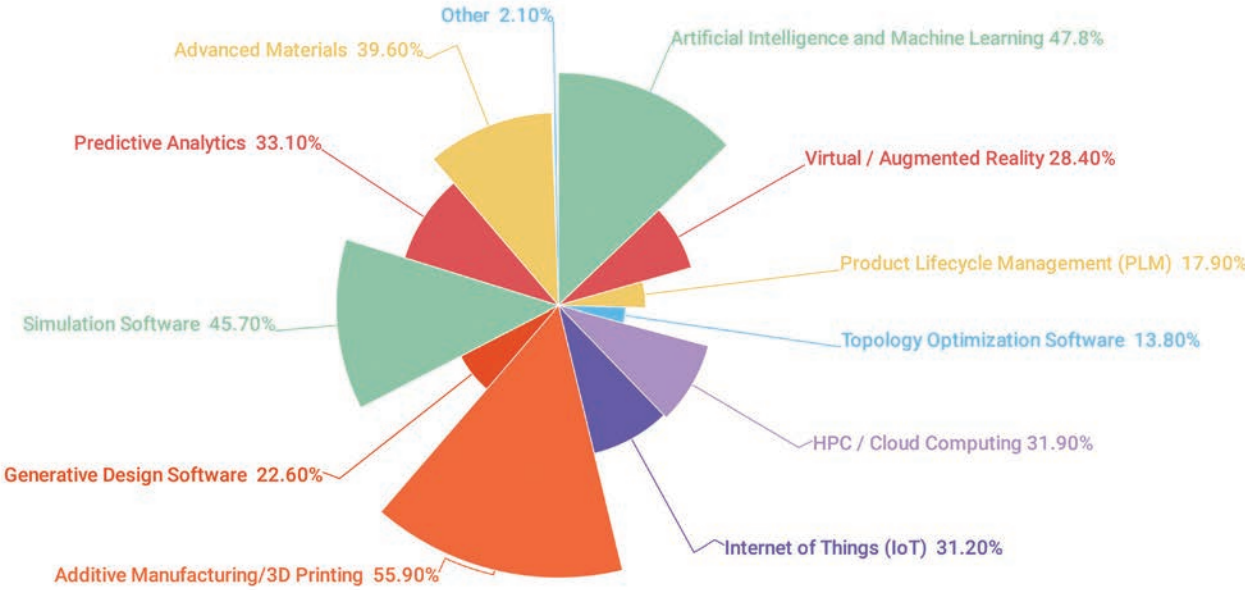
When asked what challenges they face when developing a digital thread of information flowing up and down the product development, manufacture and deployment chain, complexity of design and development was indicated by more respondents

How Important are Each of the Following Challenges in Your Day-to-Day Work?



Staffing difficulties were on the rise this year, but the perennial challenges of collaboration far outweighed them. ***Source:*** **Digital Engineering's** ***2018 Technology Outlook Survey.***

Technologies Making an Impact



The technologies respondents think will have the biggest impact on product design and development over the next 5 years, when asked to choose three. *Source:* Digital Engineering's *2018 Technology Outlook Survey.*

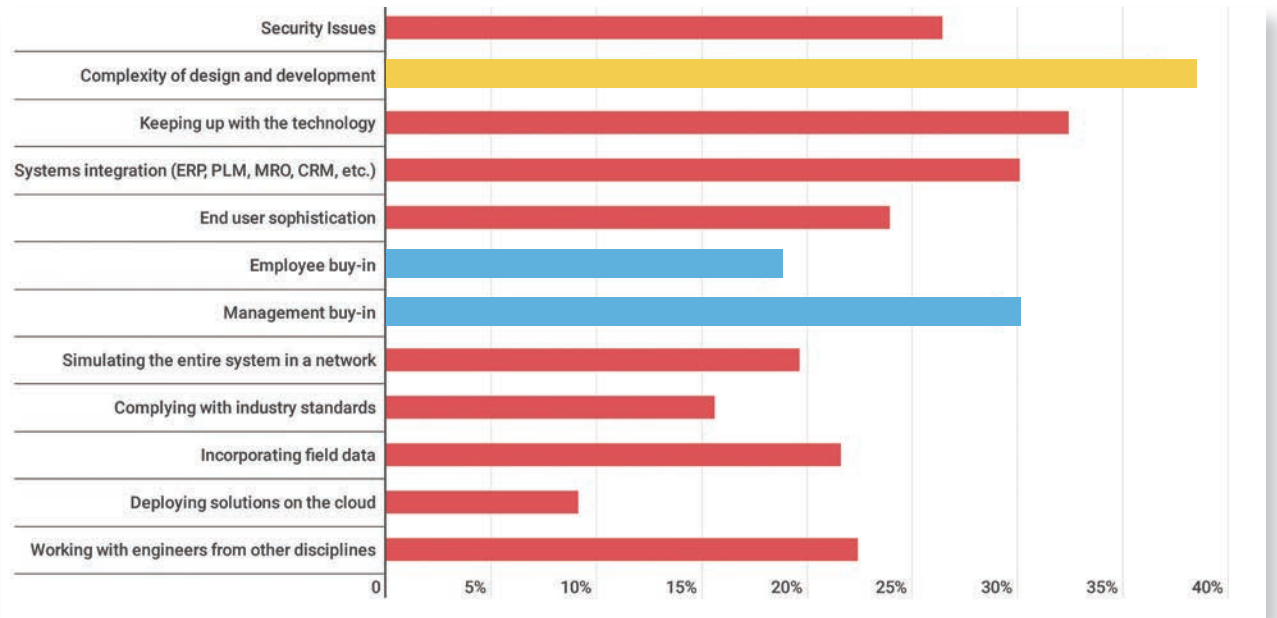
(37%), with keeping up with the technology (32%) and systems integration (30%) following close behind.

However, it's still early for the digital thread. Only 17% of respondents said their organization was using or planning to implement a digital thread/digitization, while 37% said they were not and 46% were unsure. Given that almost half of respondents weren't sure, if upper management is planning on investing in a digital thread strategy, they're not communicating it to the design engineering team. But perhaps management isn't sold on the value of the digital thread. Only 18% of respondents cited employee buy-in as a digital thread development challenge vs. the 29% who cited management buy-in.

The Top 3 Technologies Gaining Traction

Technologies with proven track records, such as additive manufacturing/3D printing (56%), AI/machine learning (48%)

What Challenges or Issues do You Face When Developing a Digital Thread?

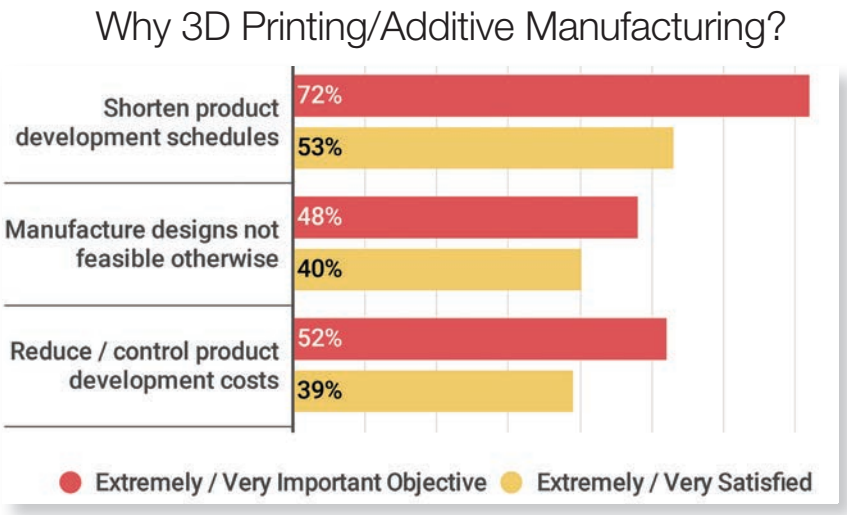


Product complexity makes digital thread development difficult. Management buy-in is more of a challenge than employee buy-in. *Source:* Digital Engineering's *2018 Technology Outlook Survey.*

and simulation software (46%), are expected to have a greater impact on the near future of product design and development by *DE* survey respondents. Materials also made an impressive showing in the impact category, with 40% of respondents choosing them as a technology they think will have a big impact on product design and development in the next five years.

Some respondents pointed out how advancements in one technology will affect another. "As data is introduced to a machine learning platform, it will help in the development of better and more advanced materials," wrote one respondent, when asked about artificial intelligence and machine learning.

"It is dependent upon material development to realize its full potential," wrote another when asked about additive manufacturing/3D printing.



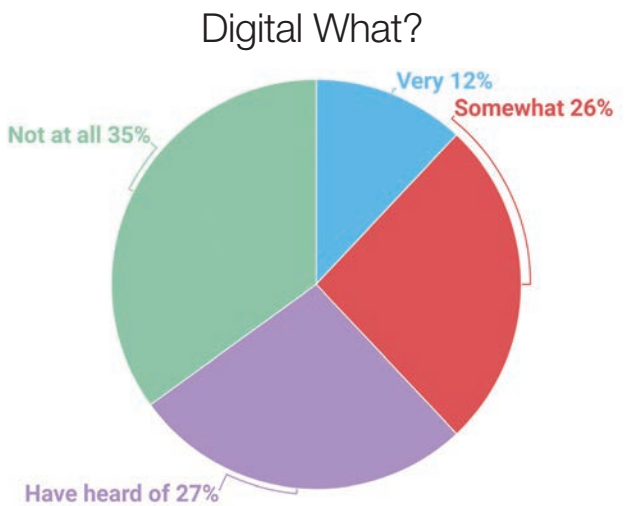
The top objectives when originally implementing 3D printing/additive manufacturing vs. post-implementation satisfaction levels. *Source:* Digital Engineering's *2018 Technology Outlook Survey.*

Respondents aren't waiting for additional material advancements before implementing 3D printing, however. When asked what they were currently using/developing products for, 3D printing/additive manufacturing was near the top of the list (40%), second only to simulation software (55%). Of those using 3D printing, prototyping (85%) is the most popular use case, followed by testing (55%) and producing end-use parts (36%). The most cited reasons for turning to 3D printing/additive manufacturing were shortening product development schedules (72%), reducing or controlling development costs (52%) and producing parts they couldn't feasibly make otherwise (48%).

AI Expectations High

Some of the responses to *DE's* survey show that design engineering teams take the claims surrounding artificial intelligence with a grain of salt: "Over-hyped and as a result under-realized," wrote one respondent when asked for their impressions of AI. "These are mostly buzzwords that managers want in new products from a marketing standpoint," wrote another, "but they don't know what AI and machine learning will actually do in a product."

However, 15% of respondents say they are already using AI/machine learning to develop products or developing products that make use of AI/machine learning, and another 31% expect to be doing so within the next two years.



Familiarity with the term "Digital Twin." *Source:* Digital Engineering's *2018 Technology Outlook Survey.*

The Revolution will be Simulated and 3D Printed

To push our normally pragmatic engineering audience into some soothsaying, we provided a series of claims about different technologies' potential to revolutionize the design engineering process and asked them which ones they agreed with most.

The revolutionary catalyst most chosen was 3D printing (63%), followed by simulation-led design (53%). Other potentially revolutionary technologies, such as big data analytics, high-performance computing/cloud computing, virtual and augmented reality, the internet of things and generative design didn't break the 40% mark. In fact, the third-most agreed upon prognostication was "The democratization of simulation will revolutionize the design engineering process" with 36%.

That may also have something to do with how familiar respondents are with various technologies. When asked which technologies they are familiar with, simulation software (41%), additive manufacturing/3D printing (37%) and product lifecycle management (30%) were cited as "very familiar" to most. On the other hand, only 17% said they were very familiar with AI/machine learning, so perhaps some of those eye-catching headlines and links are having an effect. DE

Jamie Gooch *is editorial director of* Digital Engineering. *Contact him: jgooch@digitaleng.news.*

Tech **Disruptions** Brought to the Table

BY STEPHANIE SKERNIVITZ

PATTERNED loosely after the framework of the Periodic Table of Elements, Imperial College London's Table of Disruptive Technologies may generate some future-oriented water cooler banter that may lead to real-world applications for the disruptions cited.

The idea for such a "disruptive" table stems from some casual conversations among members of the Tech Foresight Team at Imperial College (imperialtechforesight.com), especially Anna Cupani, stakeholder engagement manager of the William Penney Laboratory—Data Science Institute at the Imperial College London (ICL), and futurist in residence at ICL, Richard Watson.

The Tech Foresight team had completed a project on the future of water and happed upon "disruptive" technologies.

"The adjective sounded a bit too vague and too much of a buzzword, so we started discussing [it]," Cupani recalls.

Such a discussion aligns with the vision of the Tech Foresight team, which exists to help companies and organizations "be prepared for change and have the tools and the skills to respond to change or to be the change they want," Cupani says. So she and the team set out to determine whether Imperial College could add some research-supported insight to the "disruptive technologies" scene.

The goal? Identify how to organize these technologies in "a meaningful and easily accessible way for outsiders."

She and Watson envisioned a visual to represent their findings. A chemist at heart, Cupani gravitated to the idea of a table that roughly resembled the Periodic Table of Elements. "Instead of metal/non metal/transition elements we grouped the technologies in short-, medium- and long-term impact, which is where the colors originated," she says.

As the table took shape, the team consulted academics at Imperial College with expertise in fields such as energy, robotics, computing and bioengineering to comment on what was missing or out of place and why, according to Cupani.

"All of them … spent their precious time giving me their opinion and discussing why they thought certain technologies are still too far ahead despite the hype and why others are not discussed much but may have a massive impact," Cupani says.

Informed Opinion, Not Science

She adds a caveat: "I should stress that the way this Table came to life is quite different from the way scientists operate. The scientific method is based on hypothesis verified through tests and experiments, but we could not use it here, for obvious reasons given the topic."

Cupani wanted to create a tool to stimulate a discussion around the technologies and their impact on individuals and societies. The researchers also dared to be provocative and make hypotheses that may turn out completely wrong, she notes.

Technologies in this table (see page 12) "give an insight on what humanity is searching for, what unaddressed needs we are exploring and what ultimately makes our life meaningful," Cupani adds. DE

Stephanie Skernivitz *is associate editor of* Digital Engineering. *Contact her at sskernivitz@digitaleng.news.*

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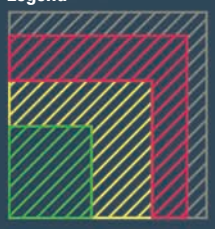
TABLE OF DISRUPTIVE TECHNOLOGIES

POTENTIAL FOR SOCIO-ECONOMIC DISRUPTION: HIGH ↑ / LOW ↓

De Digital footprint eraser 91 DE	**Ps** Personal digital shields 92 DE	**Ht** Human head transplants 93 HA	**Hc** Human cloning and de-extinction 94 HA	**Da** Distributed autono-mous corporations 95 DE	**Sp** Space solar power 96 SP	**El** Space elevators 97 SP	**Vr** Fully immersive virtual reality (VR) 98 DE	**Co** Artificial consciousness 99 EA
Ci Conversational machine interfaces 81 MI	**Le** Life-expectancy algorithms 82 DE	**Sa** Stratospheric aerosols 83 SP	**Br** Battlefield robots 84 EA	**Ad** AI advisors & decision- making machines 85 DE	**Ab** AI board members & politicians 86 EA	**Is** Invisibility shields 87 SP	**Ph** Factory photosynthesis 88 SP	**Th** Transhuman technologies 89 HA
Ss Planetary-scale spectroscopy 71 SP	**Ip** Implantable phones 72 MI	**He** e-tagging of humans 73 DE	**Mp** Male pregnancy & artificial wombs 74 HA	**Dn** DNA data storage 75 DE	**Gv** Genomic vaccines 76 SP	**Qs** Quantum safe cryptography 77 DE	**Cp** Cognitive prosthetics 78 HA	**Ud** Data uploading to the brain 79 HA
Gh Predictive gene-based healthcare 61 DE	**Ak** Automated knowledge discovery 62 EA	**Rs** Autonomous robotic surgery 63 EA	**Em** Emotionally aware machines 64 MI	**Xx** Humanoid sex robots 65 MI	**Bh** Human bio-hacking 66 HA	**Me** Internet of DNA 67 DE	**Tc** Thought control - machine interfaces 68 MI	**Dr** Dream reading & recording 69 HA
Md Mega-scale desalination 51 SP	**Sw** Self-writing software 52 EA	**Mm** Public mood monitoring 53 DE	**Pb** Programmable bacteria 54 SP	**Et** Peer-to-peer nergy trading & transmission 54 SP	**La** Lifelong personal avatar assistants 56 MI	**Sd** Smart dust 57 DE	**Lc** Low-cost space travel 58 HA	**Pc** Planet colonization 59 HA
Mc Medical tricorders 41 DE	**Sf** Smart flooring & carpets 42 DE	**Dt** Diagnostic toilets 43 DE	**Se** Smart energy grids 44 SP	**Bf** Algal bio-fuels 45 SP	**Op** Human-organ printing 46 SP	**Bs** Artificial human blood substitute 47 SP	**Nm** New materials 48 SP	**Fu** Fusion power 49 SP
Dl Distributed ledgers 31 DE	**Pa** Precision agriculture 32 SP	**Av** Autonomous vehicles 33 EA	**Id** Intention decoding algorithms 34 MI	**Df** Drone freight delivery 35 EA	**Ap** Autonomous passenger aircraft 36 EA	**Fp** 3D-printing of food & pharmaceuticals 37 SP	**Sr** Swarm robotics 38 EA	**Fd** 4-dimensional materials 39 SP
Rc Robotic care companions 21 MI	**Sc** Smart controls and appliances 22 DE	**Cm** Cultured meat 23 SP	**Ro** Delivery robots & passenger drones 24 EA	**As** Autonomous ships & submarines 25 EA	**Rg** Resource gamification 26 SP	**Wa** Water harvesting from air 27 SP	**Eb** Broadcasting of electricity 28 SP	**Bp** Bio-plastics 29 SP
Cr Cryptocurrencies 11 DE	**So** Concentrated solar power 12 SP	**Pp** Predictive policing 13 DE	**Eh** Micro-scale ambient energy harvesting 14 SP	**Wt** Airborne wind turbines 15 SP	**Ac** Avatar companions 16 MI	**Mh** Metallic hydrogen energy storage 17 SP	**Sg** Smart glasses & contact lenses 18 HA	**Pe** Pollution eating buildings 19 SP
Sn Smart nappies (diapers) 1 DE	**Dw** Deep ocean wind farms 2 SP	**Va** Vertical agriculture 3 SP	**We** Wireless energy transfer 4 SP	**Bi** Balloon-powered internet 5 SP	**Px** Powered exoskeletons 6 Ha	**Cc** Computerized shoes & clothing 9 DE	**Vt** Vacuum-tube transport 8 SP	**Sj** Scram jets 9 SP

SOONER ← TIME* →

Legend



Ghost Technologies: Fringe science & technology. Defined as highly improbable, but not actually impossible. Worth watching.
Horizon 3: Distant future 20 years + (Explore).
Horizon 2: Near future 10-20 years hence (Experiment).
Horizon 1: Happening now (Execute).

How to read entries

Sn — Abbreviation of technology
Smart nappies — Description of technology
1 DE — Theme (See next right)
Examples (See right hand page)

Themes Each of the 100 technologies has been subjectively categorized according to five broad themes, which are:

- DE Data Ecosystems
- SP Smart Planet
- EA Extreme Automation
- HA Human Augmentation
- MI Human-Machine Interactions

A dashboard of 100 wonderful, weird (and possibly worrying) ways the world might change in the foreseeable future.

Imperial College London

Qt
We can't talk about this one
100

Te
Telepathy
90 HA

Rd
Reactionless drive
80 SP

Wh
Whole Earth virtualisation
70 DE

Sh
Shape-shifting matter
60 SP

Mr
Self-reconfiguring modular robots
50 SP

Ze
Zero-point energy
40 SP

Be
Beam-powered propulsion
30 SP

Ff
Force fields
20 SP

Am
Asteroid mining
10 SP

→ LATER

Examples of organizations active in each area

1 Monit (South Korea), Abena Nova (Denmark), Siempre Secos (Spain)
2 Statoil (Norway), Siemens (Germany), Volturn (US), UMaine (US)
3 Green Skies Vertical Farms (US), Aero Farms (US), Neo Farms (Germany), Urban Crop Solutions (Belgium)
4 WiTricity (US), Powermat (Israel), Apple/Power By Proxi (US), Qualcomm (US), Mojo Mobility (US), Mopar (US), Fulton Innovation (US)
5 Google/Alphabet (US)
6 ReWalk (US), Rex Bionics (US), SuitX/US Bionics (US), Ekso Bionics (US), Lockheed Martin (US)
7 Google/Alphabet (US), Samsung (Korea), Hexoskin (Canada) Owlet (US), Komodo Tech (Canada), Shiftwear (US), Lechal (India), OM Signal (Canada)
8 The Boring Company/Elon Musk (US), China Aerospace Science and Industry Corporation (China)
9 Reaction Engines (UK), NASA (US), Boeing (US), Lockheed Martin (US), Airbus (France)
10 Deep Space Industries (US), Planetary Resources (US), Made in Space (US)
11 Bitcoin (Japan), Ripple (US), Litecoin (US)
12 Solarreserve (US), Abengoa (Spain), North China Power Engineering (China), Shanghai Electric (China), Zhejiang Supcon Solar (China), NWEPDI (China)
13 PredPol (US), ECM Universe (US)
14 Pavegen (UK), ECEEN (China)
15 Google/Alphabet (US), Joby Energy (US), Altaeros (US), Kitegen (Italy), Enerkite (Germany)
16 Pullstring (US), Amazon (US), Alphabet/Google (US), Nintendo (Japan), Invisible Girlfriend/Boyfriend (US)
17 NASA (US)
18 Alphabet/Verily (US), Amazon (US), Vuzix (US), Everysight (Israel)
19 Elegant Embellishments (Germany), iNova (Spain), Studio Roosegaarde (Netherlands), Prosolve 370e (Germany)
20 Dstl (UK), Boeing (US)
21 Softbank (Japan), AIST (Japan), Blue Frog Robotics (France), Care-o-bot (Germany), Riken/Sumitomo Riko (Japan), Mayfield Robotics (US)
22 Amazon (US), Google/Alphabet (US), Philips (Netherlands), Samsung (South Korea), Dyson (UK), Miele (Germany), iRobot (US)
23 Impossible Foods (US), Memphis Meats (US), Super Meat (Israel), Finless Foods (US), New Harvest (US)
24 Wing/Alphabet (US), Starship Technologies (UK), Volocopter (Germany), eHang (China), Piaggio (Italy)
25 Leidos (US), Boeing (US), Rolls Royce (UK) 26 Joulebug (US), Waterpebble (UK)
27 Permalution (US), Sun to Water (US)
28 Powercast (US)
29 NatureWorks (US), Gruppo MAIP (Italy), Genomatica (US), Green Dot Bioplastics (US)
30 NASA (US)
31 Everledger (UK), Stampery (Spain), Brickblock (Germany), Slock.it (Germany)
32 Blue River Technology (US), Hortau (Canada)
33 Google/Waymo (US), Voyage (US), Nvidia Automotive (US), most major auto-makers
34 Amazon (US), Google/Alphabet (US), Philips (Netherlands), Samsung (South Korea), Dyson (UK), Miele (Germany), iRobot (US)
35 Google/Alphabet (US), Amazon (US), Flirtey (US) 36 Airbus (France), Boeing (US)
37 FabCafe (Japan), NASA (US)
38 SRI International (US)
39 Stratasys (US), Autodesk (US)
40 NASA (US)
41 Basil Leaf Technologies (US), Dynamical Biomarkers Group (US/Taiwan), Scanadu (US)
42 Starwood Hotels (US), MariCare (Finland), Scanalytics (US), Futureshape (Germany)
43 Flowsky (Japan), Scanadu (US)
44 Tesla (US), ABB (Switzerland), Siemens (Germany), IBM (US), Itron (US)
45 Synthetic Genomics/ExxonMobil (US), Global Algae Innovations (US), Algenol (US)
46 Organavo (US), Envision TEC (Germany), RegenHU (Switzerland), Cellink (Sweden), Seraph Robotics (US)
47 HbO2 Therapeutics (South Africa), Biospace (US)
48 For example Vantablack by Surrey NanoSystems (UK)
49 ITER (EU/France), Tokamak Energy (UK), Alphabet/Google/Tri Alpha Energy (US), General Fusion (Canada), Helion Energy (US), Lockheed Martin (US)
50 Festo (Germany)
51 Israel Desalination Enterprises Technologies (Israel), Acciona (Spain), Fluence Corporation (US)
52 Microsoft (US), Google/Alphabet (US), Open AI (US)
53 Open Utility/Essent (UK/Netherlands), Knowelsys (China)
54 Gingko Bioworks (US), US Naval Research Laboratory (US), US Army Research Lab (US), Darpa (US)
55 Open Utility (UK/Netherlands), Power Ledger (Australia), LO3 energy (US), Energy Web Foundation (Switzerland)
56 Konami Corp (Japan), Mitsuku (UK)
57 MOOG (US), Darpa (US)
58 Space X/Elon Musk (US), Blue Origin (US), Virgin Galactic (UK), Rocket Lab (US), Axiom Space (US), SpaceIL (Israel), Firefly Aerospace (US)
59 Space X (US), UAE Mars Mission (UAE), NASA (US)
60 Intel (US)
61 Kite Pharma/Gilead Sciences (US), 23andMe (US), Phenogen Sciences (US), Regeneron (US), Veritas Genetics (US)
62 IBM (US)
63 Intuitive Surgical (US), Verb Surgical/Alphabet/Johnson & Johnson (US), Da Vinci Surgery (US)
64 IBM (US), Toyota (Japan), Mimosys (Japan), Persado (US), Joy AI (US)
65 Realbotix (US), True Companion (US)
66 BioTeq (UK), Grindhouse Wetwear (US), Dangerous Things (US), see also The Eyeborg Project and the Cyborg Foundation
67 Alphabet/Google Genomics (US), Amazon (US), Illumina (US), Oxford Nanopore Technologies/Metrichor (UK)
68 CTRL-Labs (US), Emotiv (US), Neuralink (US), maybe Facebook (US)
69 No example found
70 Improbable (UK)
71 European Organization for Astronomical Research in the Southern Hemisphere (European consortium of 16 countries)
72 No example found
73 Epicenter (Sweden) and Three Square Market 32M (US) are close
74 No example found
75 Twist Bioscience (US)
76 Vaccinogen (US), EpiVax (US), IBM (US), Juno Therapeutics (US)
77 Alphabet/Google (US), KETS (UK), IDQ (Switzerland), Isara (Canada)
78 DARPA (US)
79 Kernel (US), Neuralink/Elon Musk (US), 2045 Initiative (Russia), Darpa (US), General Electric/Braingate (US), possibly Facebook (US)
80 NASA (US), Cannae (US)
81 Apple (US), Amazon (US), Alphabet/Google (US), Microsoft (US)
82 No example found
83 CIA (US)
84 Lockheed Martin (US), QinetiQ (UK), Boston Dynamics/Softbank (US/Japan)
85 Woebot (US), Pefin (US), LV (UK)
86 Deep Knowledge Ventures (Hong Kong), Tieto (Finland)
87 BAE Systems (UK), Toyota (Japan). NB. Big difference between optical camouflage and bending light to make things disappear
88 Breakthrough Energy (US), RIPE (US), Joint Centre for Artificial Photosynthesis (US)
89 SENS Research Foundation (US), Methuselah Foundation/Peter Thiel (US)
90 Facebook (US), Neuralink/Elon Musk (US)
91 Suicide Machine (Netherlands), Just Delete Me (US)
92 No example found
93 Turin Advanced Neuromodulation Group (Italy)
94 Sooam (South Korea), Revive and Restore (US)
95 No example found
96 Rebeam (US), Solaren Corp (US)
97 Thoth Technology (Canada)
98 Improbable (UK), HelloVR (US), Magic Leap (US), Microsoft (US). See also Mind Maze (US), Facebook (US) and possibly Apple (US)
99 Possibly Alphabet/Google (US)
100 As it says, we can't say

* Time is defined as ubiquity or mainstream use, not invention.

The Small Print Conceived and created by Richard Watson and Anna Cupani at Imperial Tech Foresight. Thanks are due to Gaby Lee, Simon Tindemans, Thomas Heinis, Stephen Green, Peter Childs, Maria Jeansson, Nik Pishavadia, Roberto Trotta, Aifric Campbell, Christopher Haley, Tom Cleaver, Guido Cupani, Gerard Gorman, Finn Giuliani, Lawrence Whiteley, Sebastian Melchor and the Science Communication students at Imperial College London for their invaluable assistance and enthusiasm.

The purpose of this publication is to make individuals and institutions future ready. Also, to make people think, at least periodically.

It is a mixture of prediction and provocation intended to stimulate debate, but be aware that other elements should always be considered when assessing potential impact, especially the wider psychological and regulatory landscape in which technologies exist. Most importantly, the technologies highlighted on this table appear without any discussion of moral or ethical factors.
Generally speaking, no technology should be used unless it improves the human condition and with potentially disruptive technologies always remember that "with great power comes great responsibility." (There are various attributions for this quote ranging from Spiderman, Dr Spock, Yoda, Churchill, Roosevelt and possibly the French Revolution).
Examples are purely illustrative and do not constitute any form of recommendation, validation or investment advice. Also note that with smaller companies and start-ups in particular the landscape is continually changing so treat examples with caution. There will also undoubtedly be errors and misjudgments, so please use a bit of common sense.
If you'd like to contact us to congratulate us, criticize us or buy us lunch our address is techforesight@imperial.ac.uk. You can also reach Richard via richard@nowandnext.com.
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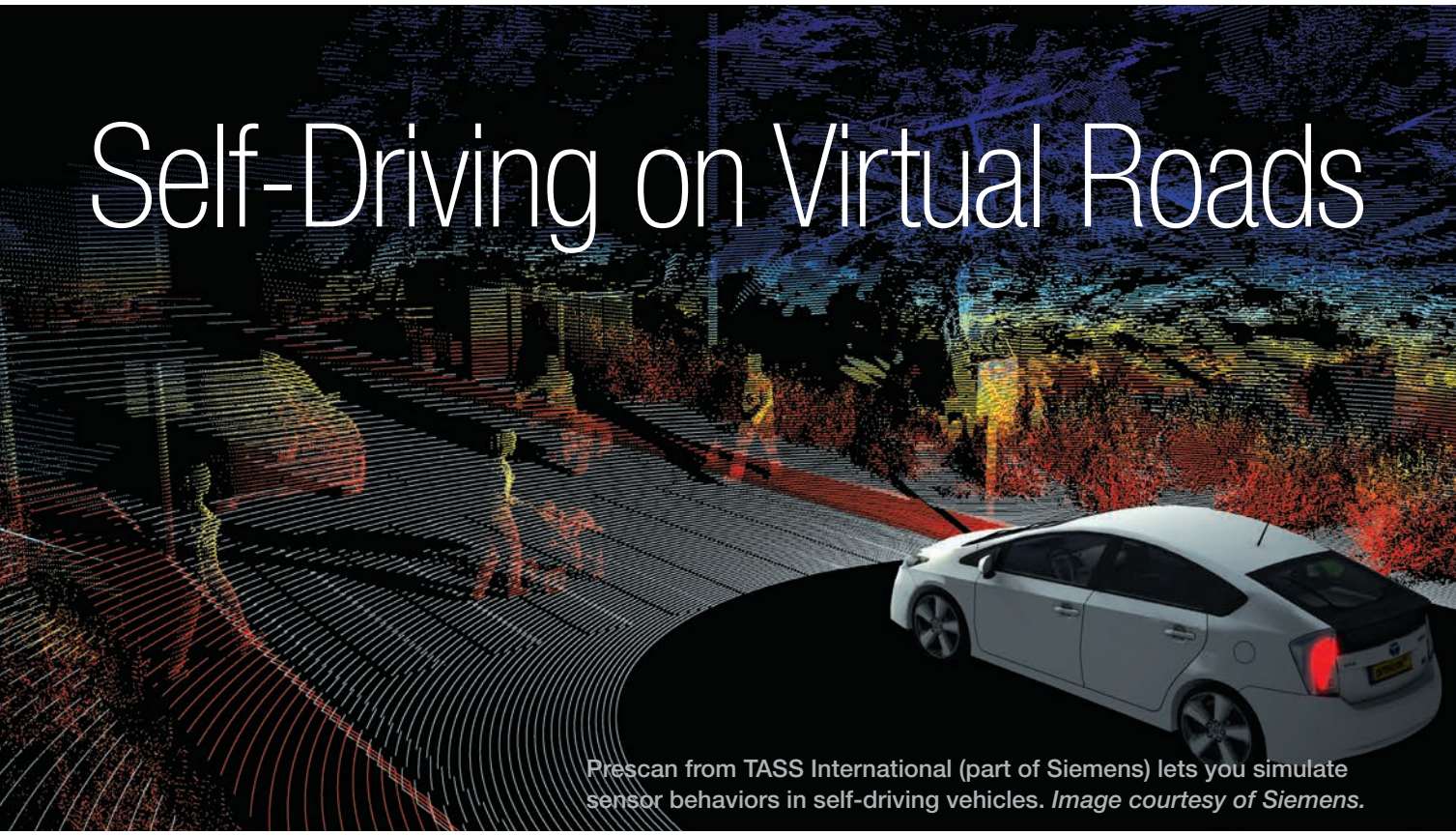
Self-Driving on Virtual Roads



Prescan from TASS International (part of Siemens) lets you simulate sensor behaviors in self-driving vehicles. *Image courtesy of Siemens.*

Programs learn to navigate in digital highways.

BY KENNETH WONG

ABOUT SIX OR SEVEN YEARS AGO, when Martijn Tideman first joined TASS International, convincing car makers to use simulation software was an uphill battle. "They'd tell me, 'It would never work. We've been doing road testing for 30 years. That's what we'll continue to focus on,'" he recalled the conversations.

His current PowerPoint deck for sales calls still includes a series of slides that make the case for using simulation software. But these days, he seldom gets to use them. "Now, when I talk to prospective clients, they'd say, 'Skip those slides. We know we need to do it. Just show us what you can do.'"

Among TASS International's products is Simcenter Prescan, described as "a physics-based simulation platform for development of advanced driver assistance systems and automated driving systems that are based on sensor technologies such as radar, laser/lidar, camera, ultrasonic, DSRC [dedicated short-range communications] and GPS."

Software such as Simcenter Prescan allows automakers to train their artificial intelligence (AI) programs to make the right decision not only in routine events but also in uncommon but imminent events. For example, how would the autonomous pilot react to an elephant crossing the road, or a group of trick-or-treaters dressed up as pumpkins?

Most human drivers have acquired sufficient life experiences to deal with these incidents, but autonomous vehicles have not. To physically set up these unusual scenarios to train the AI pilot is quite daunting. In some cases, it may be downright dangerous for the participants. This is where virtual driving software offers engineers the option to build the event in pixels and repeat it until the AI has developed a good strategy to deal with it, be it a sauntering elephant or a bunch of two-legged pumpkins.

When an Elephant Crosses the Road

TASS International's genesis went back to the Netherlands Organisation for Applied Scientific Research (TNO). In 2013, after consolidating five divisions of TNO, TASS International was created. In September 2017, manufacturing titan Siemens acquired TASS International, in a bid to bolster its offerings to autonomous car developers. TASS International products and services are now part of

Siemens' Simcenter portfolio.

TASS International's products are: Simcenter Madymo, for restraint system design and occupant safety analysis; Simcenter Prescan, for virtual development and validation of automated driving systems; and Simcenter Tyre, for tire simulation and vehicle performance analysis.

Although most autonomous vehicle developers are concentrating on simulating and testing how the AI program handles routine events (lane changes, road construction signs, sudden stops and so on), Tideman feels it's equally important to conceive and test the rare but imminent events.

"Statistically, some events only occur once in every 10,000 miles, and others once in every 100,000 miles," Tideman says. "But that means if the car is on the road long enough, it will encounter them."

On a normal day in New York, having to stop for an elephant crossing the road is highly improbable, but if a circus is in town, the likelihood increases. It increases more if the location changes to rural parts of Southeast Asia, where people and beasts share the land and the roads.

Then there are also combinations of factors that are unlikely to occur, but still within the realm of possibility. Most engineers would test and train the AI to drive in a blizzard, deal with faded lane markers, or react to the sudden appearance of a pedestrian. But are they testing how the AI performs when it's driving through a blizzard on a road with faded lane markers, and a pedestrian suddenly dashes across the street?

Training the AI requires repeating variations of the same event over and over—for example, the same scenario above playing out in different degrees of visibility. "Without simulation, you can't address even a fraction of these cases," points out S. Ravi Shankar, global director of simulation, Siemens PLM Software.

When the Pumpkins Take a Stroll

Some engineers think regulatory measures hamper innovation and creativity, but, in self-driving vehicle development, Luca Castignani, autonomous driving strategist at MSC Software, thinks they should welcome them. "Regulations should set an open standard for the industry," he reasons. "Without an open standard to define the roads, sensors and the scenarios, it's extremely difficult for autonomous driving companies to work with suppliers or the government to develop or validate the autonomous system."

Castignani has given several talks on simulation-based autonomous car development. "The reality is, we're entering uncharted territories, a new continent we didn't plan to uncover," he says.

Known for its simulation software, MSC is now part of Hexagon, a Sweden-headquartered company with offerings for the manufacturing, automotive and infrastructure industries, among others. The acquisitions of MSC Software and VIRES VTD in 2017, and AutonomouStuff this year complement Hexagon's domain expertise in metrology sensors, GPS software, smart city and positioning intelligence software. The company believes its strategy and product line offer an edge in autonomous driving simulation and testing fields.

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VTD from MSC Software (part of Hexagon) is a virtual test driving software autonomous vehicle developers can use to train AI decision making. *Image courtesy of Hexagon.*

GPU maker NVIDIA's DRIVE Constellation is a two-server setup that lets you create a virtual driving experience. *Image courtesy of NVIDIA*.

VTD (Virtual Test Drive), originally developed by VIRES (pronounced vee-res), is described as "an open platform for the creation, configuration, presentation and evaluation of virtual environments for autonomous driving validation." It complements other offerings such as MSC Adams, a multibody simulation package that engineers can use to model and simulate the mechanical behaviors of cars.

In a program like VTD, you can set up the environment, the agents and the circumstances. This gives you the chance to test out scenarios that are difficult to reproduce. "Suppose you want to know how the car will behave when the city decides to paint all the road signs in yellow instead of white? Or what happens when the trees planted today grow to a size that prevents the driver from seeing the pedestrians?" Castignani asks.

With simulation, it's also possible to create outlier scenarios for testing. "Think of workers carrying a large mirror and crossing the street. Think of children dressed up as pumpkins, out for a walk on Halloween," Castignani says. "I don't think many of these scenarios have been taken into consideration, but those are realities."

It's not impossible to test these scenarios in real life, but to create these experiments and repeat them many times is costly, time-consuming and, in some cases, risky for the actors. These are, Castignani points out, better suited for virtual roads with virtual pedestrians.

Each Car Runs on its Own Constellation

Autonomous vehicle development has become a regular topic at graphics processing unit (GPU) maker NVIDIA's annual GPU Technology Conference. In 2018, NVIDIA CEO Jen-Hsun Huang highlighted the latest addition to its lineup of autonomous car-related offerings: DRIVE Constellation.

DRIVE Constellation is a data center solution that combines hardware and software packed into two servers. The first contains an array of GPUs, and runs DRIVE Sim software, which recreates data streams from a virtual car's sensors: cameras, radars and lidars. Those data streams are then fed into the second server that contains a DRIVE AGX Pegasus, the AI car computer powering many of the industry's self-driving cars. Think of each DRIVE Constellation setup as the equivalent of one virtual vehicle on the road.

"You can import worlds, roads, vehicle models, and scenarios into DRIVE Constellation, to test and validate AV

> **"Unpredictable human behavior is difficult to model and adapt autonomous vehicles to anticipate human drivers!"**
>
> – *DE* 2018 survey response

hardware and software under a wide range of conditions," Danny Shapiro, senior director for automotive, NVIDIA, says. "The simulation is happening in real time; the GPUs are generating the sensor outputs and the DRIVE AGX Pegasus is processing data and giving actuation commands as if the car were really on the road. Constellation enables true hardware-in-the-loop testing before putting vehicles on the road."

A benefit of this type of setup is the ability to repeat the target scenario with various parameters—to conduct reruns—and cover the full scope of the problems the AI will likely encounter. "Suppose you're concerned with how a car will deal with tough conditions at sunrise or sunset, when real drivers have said they tend to be blinded by the light. If you were to do the test in real life, you will only be able to do this twice a day during that precise moment," Shapiro says. "But with simulation, you can spend all day testing blinding conditions, with all different types of traffic scenarios and all types of weather conditions. The flexibility and scalability of DRIVE Constellation enables developers to create safer self-driving systems."

A Moral Compass for Self-Driving Cars

MIT researchers recently launched an online experiment, designed to explore the moral dilemmas faced by autonomous vehicles. Dubbed The Moral Machine (moralmachine.mit.edu), the online system is described as "a platform for gathering human perspective on moral decisions made by AI." By MIT's own count, it has collected 40 million decisions in 10 languages from millions of people in 233 countries and territories.

Researchers published the first set of findings in a paper titled "The Moral Machine experiment," *Nature: International Journal of Science*, October 2018. It includes charts explaining participants' choices, such as deciding between the probability of sparing pedestrians and sparing passengers.

World Building

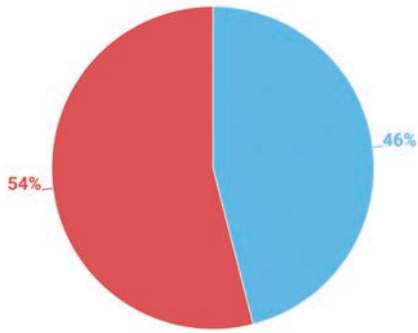
Acquiring digital twins of real-world cities is an ongoing task, currently done by road scanning firms like Atlatec, data giants like Google and autonomous car developers themselves. Hexagon's product line includes the Leica Pegasus mapping platform. With connection to VTD, the product lets engineers speed up road digitization. In one project, geospatial consultant Transcend Spatial Solutions used the Pegasus system to map and digitize the span of San Francisco's Golden Gate Bridge ("Demystifying Mobile Mapping," *xyHt*, June 2016, xyht.com).

TASS International's parent company Siemens has a partnership with Bentley Systems, known for architecture and infrastructure software. "We can import data from Bentley Systems and automatically generate a full 3D city map within Simcenter Prescan as a basis for virtually testing an automated vehicle," Tideman says.

The ability to import existing 3D models of cities into driving simulators could speed up the environment creation process, but the lack of these tools is not necessarily a hindrance. "It's not essential to model New York City in great details to enable your autonomous car to be able to drive in it. You just have to teach your car to deal with a wide range of scenarios that could occur in New York," says Tideman.

Similarly, Shapiro adds, "You don't necessarily have to map every single road as they exist. You can use simulation to train the car to recognize stop signs, traffic lights, lane markings and so on. That way, your car can handle a road that it may have never seen before."

Technological Impact



More *DE* 2018 survey respondents chose simulation (46%) as the technology that will have the biggest impact on product design and development over the next five years than any other technology.

Take it Slow

The increased number of tech giants and leading automakers jumping into the autonomous vehicle market gives the impression that, if you're late to the game, you could miss out. Consequently, many may feel pressured to rush a product out before sufficient testing has been done. However, statistics on consumer attitudes suggest adoption will not happen overnight; therefore, there's plenty of time left to devote to R&D for safety testing. DE

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

INFO → TASS International/Prescan: tass.plm.automation.siemens.com/prescan

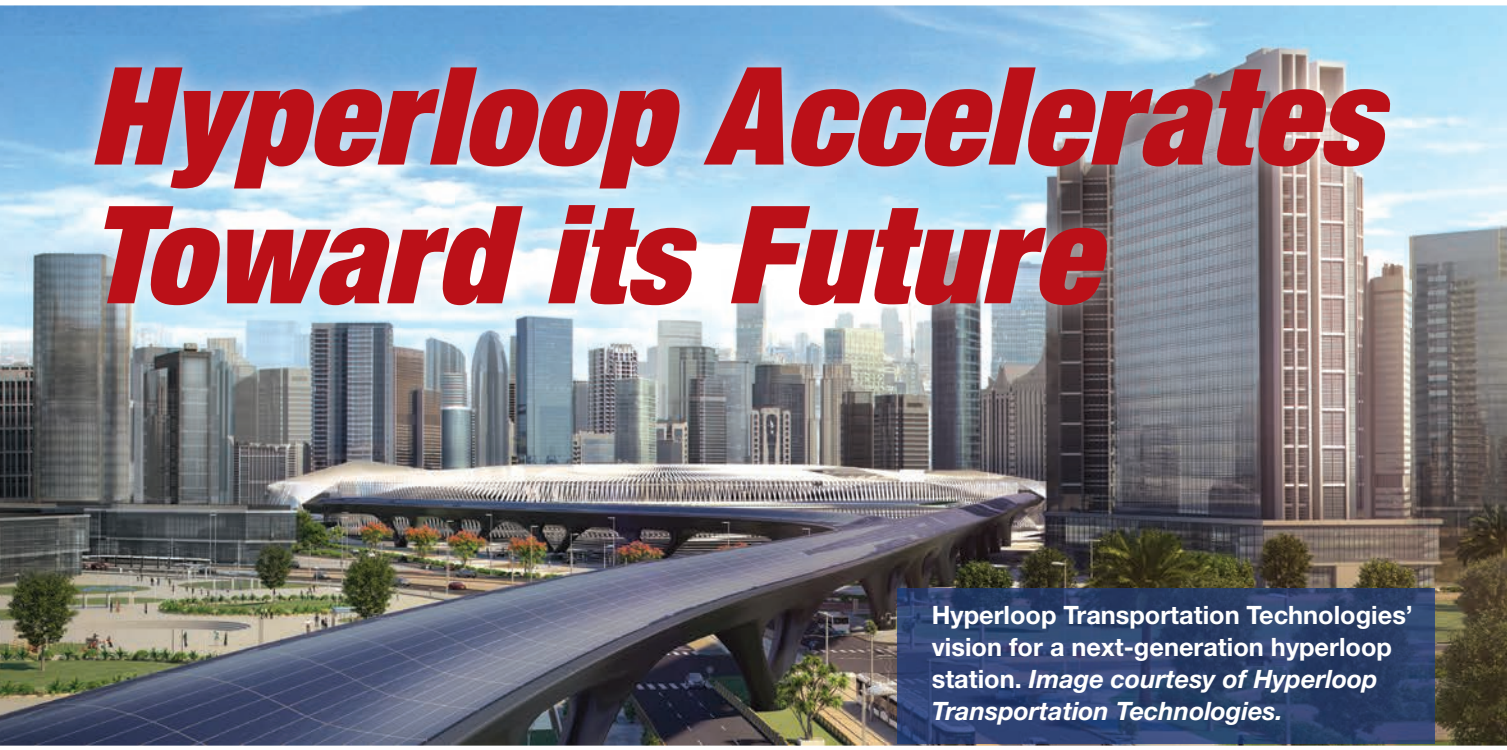
→ **MSC/Virtual Test Drive (VTD):** mscsoftware.com/product/virtual-test-drive

→ **NVIDIA Drive Constellation:** nvidia.com/en-us/self-driving-cars/drive-constellation

→ **MIT, The Moral Machine:** moralmachine.mit.edu

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

Hyperloop Accelerates Toward its Future



Hyperloop Transportation Technologies' vision for a next-generation hyperloop station. *Image courtesy of Hyperloop Transportation Technologies.*

Although years from commercial viability, hyperloop development projects are well underway as engineers build on existing technologies.

BY BETH STACKPOLE

THE QUINTERO ONE, weighing in at 5 tons, measuring 105 feet long and made of a proprietary carbon fiber material branded Vibranium (in an apparent nod toward the fictional material of Marvel Comics), made its formal debut in October, providing the first glimpse at what a full-scale hyperloop passenger capsule will look like. DevLoop, a 500-meter full-scale hyperloop test site and track in the Nevada desert, is now operational, and student teams have wrapped up their third year of competing in SpaceX's hyperloop pod challenge, setting new records for speed and acceleration.

In addition to steady engineering developments, the business of making the hyperloop next-generation transportation mode a reality is also well underway. The two primary players—Hyperloop Transportation Technologies and Virgin Hyperloop One—are knee deep in navigating the morass of the regulatory and safety landscape while also lobbying the U.S. government and foreign countries to fund feasibility studies and secure commitment for future hyperloop routes.

Most recently, global infrastructure giant Black & Veatch released the first U.S. independent feasibility study that found benefits for building a proposed route through the Interstate 70 corridor in Missouri, linking Kansas City and St. Louis—a win for Virgin Hyperloop One. The route, which aims to reduce travel time from 3.5 hours to 28 minutes, has the potential to boost ridership demand, reduce interstate accidents and lower fuel consumption—at a cost of around 40% less than high-speed rail infrastructure projects, the study found.

In addition to the Missouri study, Colorado is halfway through a feasibility evaluation for a proposed route, and both HTT and Virgin Hyperloop One have multiple feasibility studies and proposed commercial projects underway outside of the U.S., including those in the United Arab Emirates, Saudi Arabia, China, India and Ukraine.

"In the five years since we started, we've been working with companies and professionals that have the knowledge, intellectual property (IP), and technology to bring them all together rather than reinventing the wheel," says HTT CEO Dirk Ahlborn. "We've been scouting the world for existing technology that fits the bill—our main goal is not to move at the speed of sound, but to build something that makes economic sense."

The company showed off Quintero in October along with announcing a Q3 2019 target date to begin construction on a commercial hyperloop track in Abu Dhabi.

Building on Existing Foundations

Although confident in their progress to date, Ahlborn's HTT and its primary competitor Virgin Hyperloop One are cir-

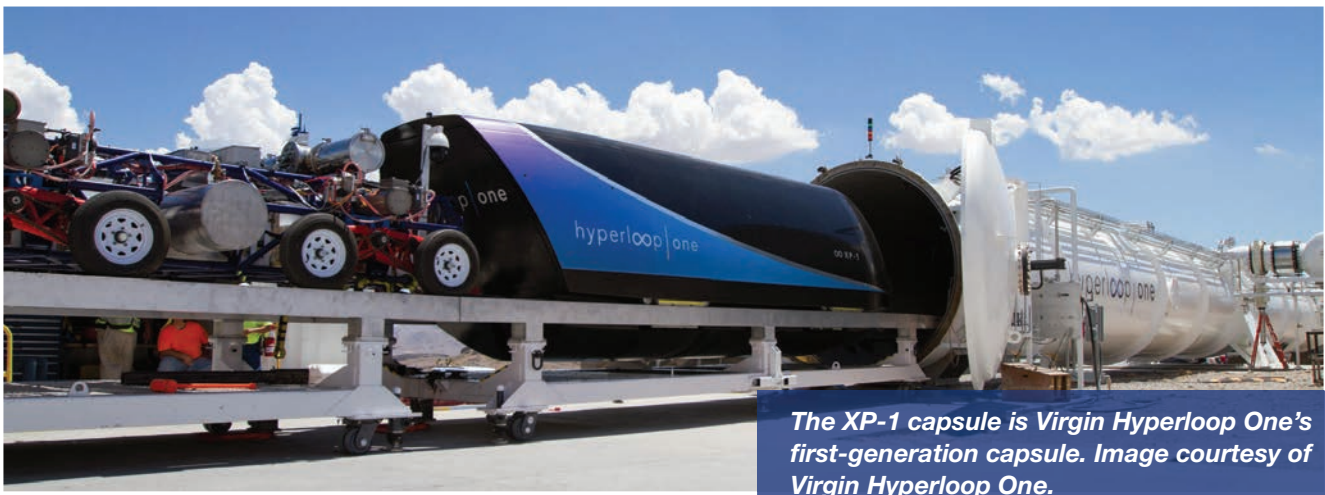
cumspect about the realities of fast-tracking an infrastructure project the magnitude of hyperloop. Born from a 57-page white paper released by tech titan and serial entrepreneur Elon Musk in 2013, the hyperloop (digitalengineering247.com/r/14834) was conceived as a pneumatic, tube-based transportation system that would be an alternative to high-speed rail systems.

> **"Hyperloop is much more based in reality than people think once you break the problem down. Most of the systems are based on something that already exists—it's putting them together in a unique way to do something different that is the key challenge."**
> – Kristen Hammer, manager of materials engineering at Virgin Hyperloop One

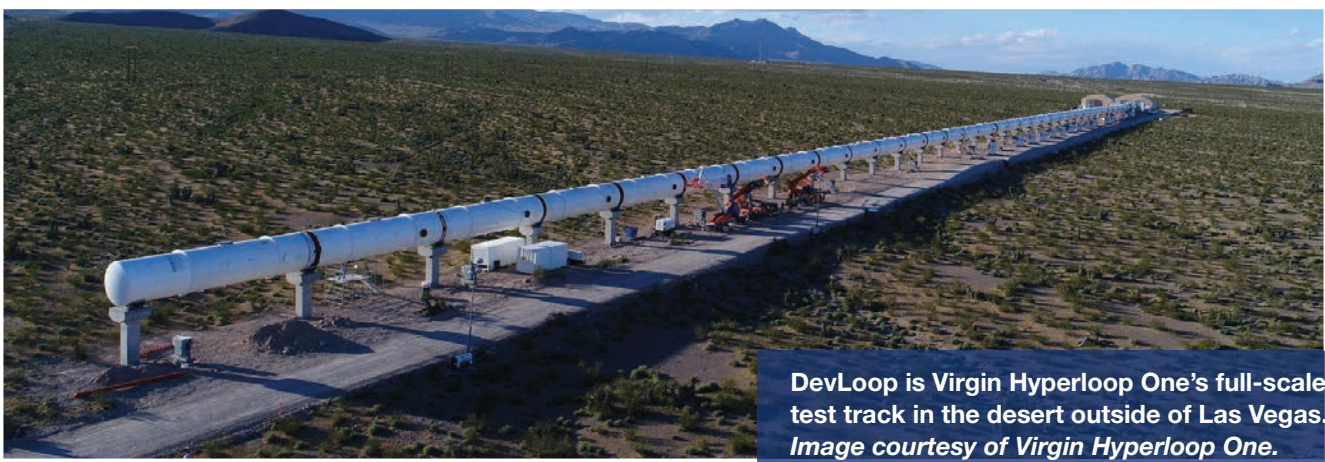
The original concept, for a network of reduced pressure tubes that transport aerodynamically designed pods using magnetic levitation or air systems driven by linear induction motors and air compressors, hasn't changed much since participants started early design work. Nor have the core engineering challenges shifted. They run the gamut from materials choices to optimizing the aerodynamics of the pod, to figuring out the best approach for combining magnetic levitation (maglev) with propulsion systems for sustained, accelerated speeds.

What has changed, however, is that there are tangible results of ongoing engineering efforts, much of it built on the back of existing technology and systems. At its core, hyperloop is a civil infrastructure project similar to a bridge or underground tunnel while the pod is predicated on many of the principles of spacecraft or aircraft design, notes Kristen Hammer, manager of materials engineering at Virgin Hyperloop One, adding that the maglev and vacuum components of the system are also fairly well understood in engineering circles.

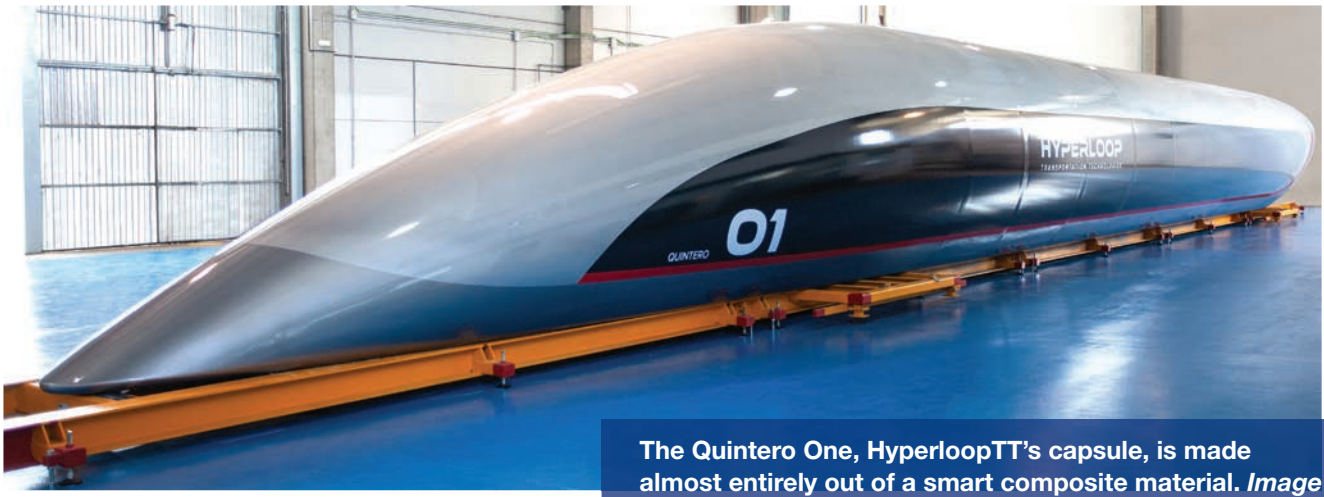
"Hyperloop is much more based in reality than people think once you break the problem down," she explains. "Most of the systems are based on something that already exists—it's putting them together in a unique way to do something



The XP-1 capsule is Virgin Hyperloop One's first-generation capsule. Image courtesy of Virgin Hyperloop One.



DevLoop is Virgin Hyperloop One's full-scale test track in the desert outside of Las Vegas. *Image courtesy of Virgin Hyperloop One.*



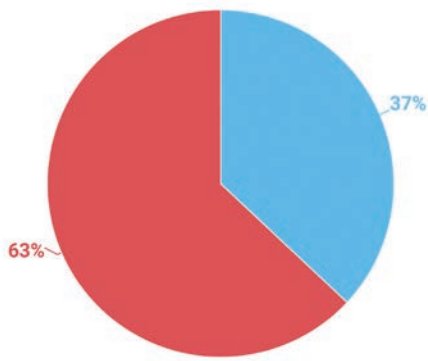
The Quintero One, HyperloopTT's capsule, is made almost entirely out of a smart composite material. ***Image courtesy of Hyperloop Transportation Technologies.***

different that is the key challenge."

One of the engineering areas where Hammer is focused lies with how materials behave in the tube vacuum—for example, how a motor is able to withstand pressure or electrical components behave in the limited air environment. Even material choices for the tube itself are an important engineering study—the internal elements are required to handle temperature changes while the outside substance needs to hold up to external elements like corrosion or ambient heat generated by sunlight or the hyperloop system itself, she explains. "Whatever material you're using has to be able to withstand a multitude of environments," she explains.

To navigate these tube design challenges and more, Virgin Hyperloop One adheres to a rigorous process of "model it, simulate it and test it," using a wide array of 3D simulation, optimization and system modeling tools. More recently, the team of 180 engineers started testing physical components at the DevLoop test site in the Nevada desert, Hammer says. Work is closely coordinated between the different engineering teams, which include structures, responsible for civil infrastructure like the columns and tubes; power electronics working on physical controls systems; levitation and motors; software engineering and manufacturing and testing.

Digital Thread Dilemma



When asked what challenges or issues they face when developing a digital thread, respondents most often chose complexity of design and development (37%).

As development work advances, 3D printing is playing a larger role in Virgin Hyperloop One's engineering roadmap, especially aiding those components requiring a more organic shape, Hammer says. The company also set up the Metalworks tooling and fabrication site, which houses the engineers, machinists and welders working to support DevLoop.

HTT, the other primary competitor in the hyperloop arena, has also hit some key development milestones. HTT got its start with an open-source development model, building up its own IP, but also tapping into a broad ecosystem of diverse engineers and other talent. Its Quintero One pod features the trademarked Vibranium skin comprised of carbon fiber material embedded with sensors, making it eight times stronger than aluminum and 10 times stronger than the alternative, the company claims. "The material is such that it is a sensor—it's part of the fibers," explains Ahlborn, adding that HTT partnered with Spanish artificial intelligence firm Airtificial on the smart material and capsule construction.

The benefit of the Vibranium smart material is intelligence and safety, he says, amplified by the fact that the pod capsule has a double layer (an inner and outer shell) for redundancy, which is a necessary safeguard when the goal is to transport people at speeds up to 700 mph. "Material sensing means we can measure even the smallest crack in the structure so we can take the capsule out of circulation quickly if need be," he explains. "We want to do anything to keep passengers safe, and knowing what is happening is preventative."

Another area where HTT has made progress is in magnetic levitation (maglev) technology. The company has an exclusive license for the Inductrack technology, created by researchers at the Lawrence Livermore National Labora-

tory in the 1990s. Inductrack is passive magnetic levitation technology that doesn't require electromagnets or any power source to achieve levitation; the technique reduces friction and provides a better way to ensure safety in the event of a failure or power outage, Ahlborn says.

The approach still requires linear motors for propulsion, and HTT is currently exploring the tradeoffs of designs that incorporate the propulsion capabilities into the capsule, which would make the track simpler, or keeping them trackside to save on onboard batteries and weight. "We're looking at both approaches, depending on the route," he says.

Along with simulation and optimization tools, HTT is using multiple collaborative platforms to facilitate work among its distributed design team. The firm also developed its own augmented reality (AR) tool for design reviews, which allows groups to view different files like 3D models and videos as part of their sessions, and virtual reality (VR) is enhancing collaboration. "It allows us to step inside the capsule and see what the space looks like in real time," he explains. "That helps a lot because we don't have to build something first to see what it looks like."

> **"I am very excited about AI and machine learning. I expect they will help my company sort through an effectively infinite set of simulation results to isolate those of greatest interest."**
>
> – *DE* 2018 survey response

Technology isn't the biggest obstacle to hyperloop moving forward, Ahlborn says, but rather the regulatory frameworks, insurance and safety concerns, funding and government bureaucracy that comes along with any large-scale engineering and infrastructure project. "In the end, we know how to propel and levitate trains, we know how to create vacuums inside tubes, we have trains that can go 600 kilometers an hour," he says. "The bigger problem is these are huge projects—it's not just something where you can raise a couple of million dollars and sit in your garage and build something."

Students Turbocharge Innovation

In addition to the two major commercial players, student teams from around the globe are doing their part to solve some of the tough engineering problems and advance hyperloop innovation. SpaceX, Musk's aerospace and space transportation company, has hosted three Hyperloop Pod competitions, which challenge student teams to design and build the best high-speed pod or capsule.

The event is held at a 1.25-km Hyperloop test track at SpaceX headquarters in Hawthorne, CA. This year, 20 teams competed, with the Technical University of Munich (TUM) taking home the top prize for the third time thanks to its self-propelled 154-lb. carbon fiber pod powered with a 50kW electric motor and pneumatic friction brakes that reached top speeds of more than 284 mph. Prior competitions allowed pods to accelerate down the test track with help from a SpaceX vehicle as a pusher.

Given the competition, the TUM team's key design challenge was to figure out the optimal power density that accounts for performance vs. weight. "We aimed to reduce mass in every possible way without having something disintegrate at high speed," explains Gabriele Semino, TUM team's project lead and team manager. "Each step of the concept where we reduced mass or increased power, the result was way better than we predicted possible." For example, the second pod was 85 kilos with 50 kilowatts of power while the third pod was only 75 kilos with 240 kilowatts of power—a five-fold increase in power intensity, he says.

One of the design changes enabling this achievement was replacing one big motor with 12 smaller motors keyed to the stabilization wheels on the pod. The other big shift the third time around was conducting rigorous simulation and optimization to help achieve the better performance. "We took a pretty analytic approach to optimizing the design to withstand forces," Semino says. "Simulation played a key role in that and with the reduction in weight."

All this experience makes the student teams a likely feeder for future engineers staffing commercial hyperloop efforts. Semino, who is finishing up his studies, isn't 100% sure he'll end up at a hyperloop company, but he's confident he'll land in a firm pursuing transportation innovation. For now, the experience has provided an opportunity to do practical work and learn skills that just aren't part of the mainstream engineering curriculum.

"We get to see the design process of a vehicle from beginning to end and that's pretty rare," he says. "It gets us motivated to think about the challenges and come up with new ideas and innovation so the moment we come out, we aren't starting from scratch." DE

Beth Stackpole *is a contributing editor to* DE. *You can reach her at beth@digitaleng.news.*

INFO ➜ **Hyperloop Transportation Technologies:** Hyperloopglobal.com

➜ **SpaceX:** SpaceX.com

➜ **Technical University of Munich:** TUM.de/en/homepage

➜ **Virgin Hyperloop One:** Hyperloop-One.com

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

SUPERSONIC COMEBACK

Boom's XB-1 is being built to validate technologies for Boom's airliner. The data collected from XB-1 test flights will help the company refine its design and engineering, test key supersonic technologies and ensure efficiency, safety and reliability, according to the company. *Image courtesy of Boom.*

Engineering startups and government agencies revisit the possibility of supersonic flight.

BY BRIAN ALBRIGHT

COMMERCIAL AIR TRAVEL is poised to get a lot faster thanks to the efforts of a handful of new supersonic jet companies, new technology and potential regulatory changes that could enable overland supersonic flight.

It's been more than 15 years since the Concorde ceased operation after a deadly crash and its financial viability became unsustainable. Supersonic jets are expensive to operate, consume a lot of fuel, create a lot of emissions and present a number of design challenges. But activity around high-speed flight is increasing.

In fact, some companies are looking past supersonic to even faster planes. Boeing unveiled its concept for a hypersonic passenger plane (which could fly at speeds above Mach 5) at the American Institute of Aeronautics and Astronautics conference this year. Although it could be decades before hypersonic passenger planes take to the skies, the company is investigating a number of different commercial and military applications.

The U.S. Air Force is also developing a hypersonic flight research vehicle, and Aerojet Rocketdyne has tested a dual-mode ramjet/scramjet engine that could support hypersonic aircraft as part of its work with NASA, the Air Force and Defense Advanced Research Projects Agency (DARPA).

The Chinese Academy of Sciences has also reported testing

This is a preliminary design for a passenger-carrying hypersonic vehicle concept that could have commercial and military applications. It is just one of several hypersonic vehicle concepts spanning a wide range of potential applications being studied by Boeing. *Image courtesy of Boeing.*

a scaled-down hypersonic jet in a wind tunnel that reached a top speed of 5,343 mph.

"The potential for hypersonic aircraft becoming a reality will require further advances in several technology areas as well as market demand," says Boeing Spokesperson Brianna Jackson. "There are also infrastructure considerations both for operation at airports and maintenance."

Supersonic Flight Testing

In the near term, commercial supersonic flights are closer to being a reality. A handful of companies are betting on demand for commercial supersonic aircraft (particularly business jets). Boom, Aerion and Spike Aerospace all have aircraft currently in various stages of design. Their biggest challenge will be ensuring a sustainable business model. Spike expects the market to be as big as 13 million passengers annually.

There are also regulatory hurdles. In the U.S., the Federal Aviation Administration (FAA) banned supersonic flight in the continental U.S. because of the noise these planes generate. However, most of the supersonic start-ups claim their designs can meet current noise standards for both sub- and supersonic flight, and can potentially meet more stringent future requirements.

In April, NASA signed a $247.5 million contract with Lockheed Martin to develop a quiet supersonic plane (the X-59 QueSST) as a low-boom flight demonstrator to test out its new design concepts. In November, NASA was scheduled to conduct a test using a modified F/A-18 Hornet combat jet to see if it could reduce the sonic boom to a "sonic thump."

In October, the U.S. Senate added language to the FAA reauthorization bill that could help facilitate supersonic flights, calling on the agency to set certification standards to enable civilian supersonic flights in U.S. airspace and to consider repealing its 1973 ban. The Senate had considered a straight repeal of the ban, but removed that language at the request of environmental and public health groups concerned about noise and emissions.

"That means, supersonic aircraft today must be efficient and comply with the latest strict takeoff and landing noise requirements, as well as current emissions standards," says Jeff Miller, vice president of marketing and communications at Aerion Supersonic. "An extremely efficient aerodynamic airframe is absolutely essential, and Aerion has accomplished this with unique design tools and a team of some of the world's best aerodynamicists."

Aerion is currently working with GE Aviation, Lockheed Martin and Honeywell to develop its AS2 supersonic business jet.

Optimizing Economics and Noise

The physics challenges of supersonic flight are well known, says Eli Dourado, global policy director at Boom. "But while the world has known how to build supersonic aircraft for decades, the technology to make them economical is more recent," he says. "Boom isn't reinventing the wheel—we're using only existing technology that's already flying on other aircraft. Instead, we're solving an optimization problem."

A shortage of suitable powerplants has also presented a challenge, particularly with tightening noise emissions. GE and Aerion announced the new GE Affinity turbofan engine earlier this year, which the companies say is the first new civil supersonic jet engine released in 55 years. According to Aerion, it meets Stage 5 takeoff and landing noise rules and current emission

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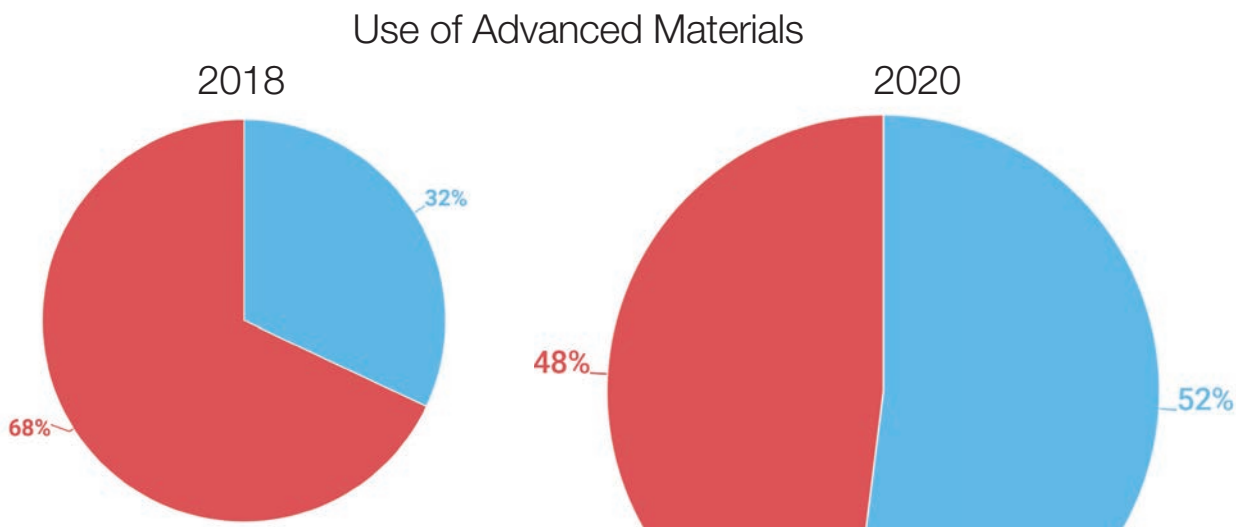


Nearly a third of *DE* 2018 survey respondents are currently developing products using advanced materials. Of those who are not, 20% say they expect to be developing products using advanced materials within the next two years.

standards. Aerion expects to finish its preliminary design phase in 2020, and the company claims to be on track to fly by 2023.

"Quieting a supersonic engine to meet subsonic regulations is an enormous challenge, and can drive engine fan size (and drag) in the opposite direction required for efficient supersonic flight and long range," Miller says. "Aerion and GE Aviation have been studying this challenge for about five years, and were quite proud to announce the Affinity engine. Our challenge was to design the AS2 business jet to fly very efficiently at both supersonic and subsonic speeds."

Future hypersonic aircraft present other types of problems. "The highly integrated nature of air-breathing hypersonic vehicles make them very difficult to properly design, and extreme heating from air friction requires hypersonic vehicles be made of very high-temperature materials and structures that are both light and durable," says Boeing's Jackson. "Integrating the engines and airframe in a manner that achieves high performance across a very large operating envelope adds to the design challenge."

Technology Gives Supersonic Flight a Lift

Advancements in engine performance, materials and design technology are also making it easier for smaller startups like Spike, Aerion and Boom to make a serious play in aerospace industry.

Carbon composites are certified for flight on commercial airliners, for example, and turbofan engines are becoming more quiet and efficient.

"We also have access to significantly more computing power than designers even a decade ago—parallel computing enables us to run more simulations in less time, optimizing our design to maximize aerodynamic efficiency and minimize unnecessary structure," says Boom's Dourado. "With today's technology, we're able to build a supersonic airliner that makes financial sense at today's business-class ticket prices."

Boom is using cloud computing and simulation for its designs, reducing the need for engineering staff and wind tunnel testing. The company turned to the cloud because the necessary high-performance computing (HPC) infrastructure would have been cost prohibitive to deploy on site. The company is running all of its simulations on Rescale's compute platform, and uses Rescale's ScaleX Enterprise administration portal to help coordinate budgets, teams and security.

Boom runs Navier-Stokes unstructured computational fluid dynamics (CFD) simulations of the flight envelope using customized HPC clusters on the cloud and accessing as many as 512 cores (with capacity to expand beyond that). Using simulation in this way has helped accelerate design development, as engineers can evaluate 100 configurations at once and achieve a 6x speedup for each job. They can also scale up and down without a huge investment in IT overhead.

"Boom's computational fluid dynamics software is the workhorse of our design process," Dourado says. "Instead of building and testing costly wind tunnel models each time we make a tweak to the loft, we rely on CFD simulation. To be sure, we still return to the wind tunnel from time to time, but the primary purpose of these physical tests is to validate the fidelity of our CFD results."

Boston-based Spike Aerospace has partnered with MAYA Simulation and Siemens PLM Software to use CAE and simulation to reduce the sonic boom generated by its plane via optimized aerodynamics. Simulation has made it possible for the small company to design the plane without a prohibitive investment in physical prototypes and testing. The company plans to fly a supersonic business jet (the 18-passenger S-512) by 2021, with commercial availability in 2023.

According to Aerion, propulsion advances will drive new

development as well. "The AS2 airframe will be built of carbon fiber composite materials," Miller says. "These materials and construction techniques are now well understood and in common use within the industry. The same applies to fly-by-wire technology, although Aerion will employ the most advanced fly-by-wire systems (previously only in military aircraft and the latest business jets), including active-control side sticks, which provide tactile and visual feedback to pilots."

Adding Materials to the Equation

Materials will also be critical for future hypersonic jets, which generate enormous amounts of heat. Researchers at NASA and Binghamton University have tested boron nitride nanotubes for this application, because their heat resistance could enable travel at five to 10 times the speed of sound.

Aerion relies heavily on simulation and modeling for transonic and supersonic airflows, which Miller says has allowed for rapid design iterations and airframe shape optimization. The company uses tools developed through its Palo Alto, CA, subsidiary, Aerion Technologies Corp.

"The insight from these tools allows us to make rapid decisions that would traditionally require much more expensive testing and detailed design work," says Alex Egeler, vice president of software for Aerion Technologies. "Using an internally developed framework, the AS2 design team has run millions of automated designs and analyses between the cloud and on-premises hardware for the aerodynamic shape of the aircraft."

The company has developed a modular, object-oriented configuration design software tool to perform trade studies and improve the AS2 performance based on the program updates and insight from working in collaboration with GE Aviation and Lockheed Martin, according to Egeler. The software can optimize the design of the aircraft and fly a simulated mission to determine key performance metrics.

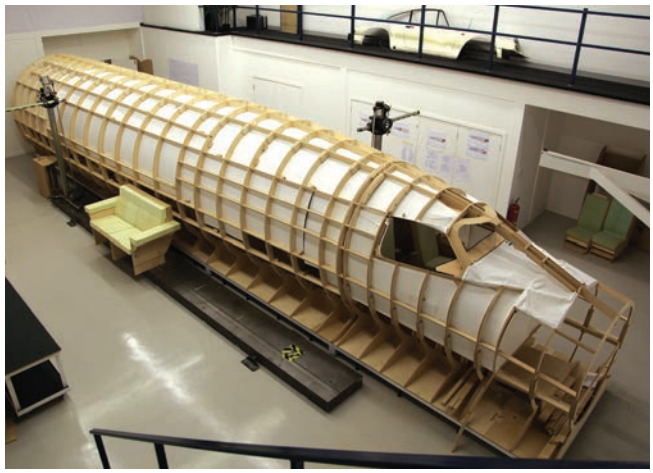
Honeywell is also researching the potential for "boom mapping" software that can help pilots know when atmospheric conditions could allow the boom to get too close to the ground. Aerion has dubbed this technology "Boomless Cruise," and it can potentially measure the Mach cutoff speed (usually between Mach 1.1 and 1.2) even in variable atmospheric conditions.

"Flight at Mach 1.2 over the U.S. would be about 50% faster than today's airliners," Miller says. "This would be a breakthrough for flight over land."

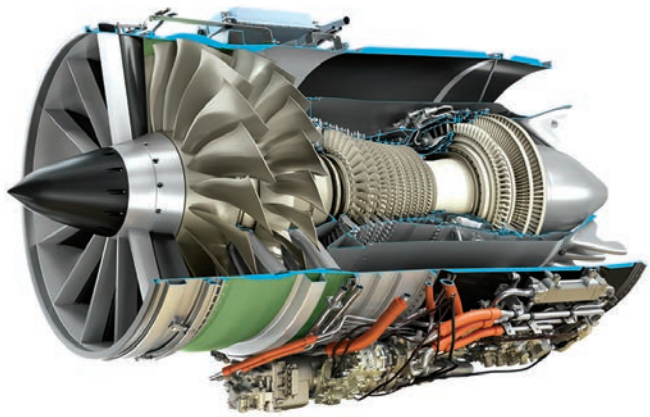
New high-temperature composites and other materials are making it easier to create faster aircraft. Boeing, Airbus and Embraer have all manufactured airliners at least partially made from carbon fiber, and the material has many advantages over aircraft-grade aluminum when designing a supersonic aircraft, according to Boom's Dourado.

"Carbon composites are much more thermally stable than aluminum—the Concorde's metal fuselage would grow by about a foot when experiencing the high temperatures of Mach-2 flight," Dourado says. "But in 2018, we're able to design a lighter airframe out of carbon composites that won't expand or contract to the same degree."

He adds that supersonic airplanes benefit from careful aircraft shaping that minimizes drag and improves fuel efficiency.



A full-scale engineering mockup was created by Aerion to advance the cockpit and cabin design of the AS2. ***Image courtesy of Aerion.***



GE and Aerion announced the new GE Affinity turbofan engine earlier this year, which the companies say is the first new civil supersonic jet engine released in 55 years. ***Image courtesy of Aerion.***

"While it's easy to fabricate cylindrical tubes out of aluminum, it's much harder to manufacture the kind of curved, area-ruled forms that reduce wave drag at supersonic speeds," Dourado says. "Carbon composites, on the other hand, are easier to fabricate in the shapes we need."

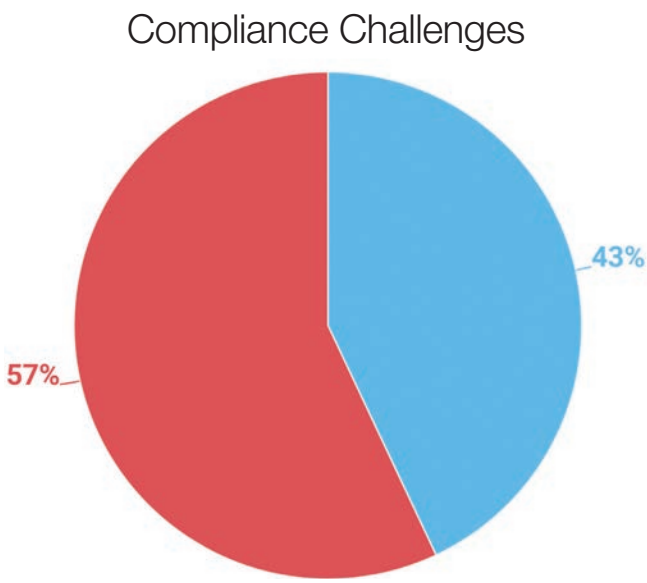
According to Boeing, key innovations that could enable hypersonic flight include lighter and more durable high-temperature materials, increased hypersonic engine performance and size, advanced sensing and analysis technologies for system health monitoring and intervention, and active control of hypersonic engine performance and stability.

Regulatory Changes May be On the Way

While supersonic aircraft designers have reduced aircraft noise, the rules limiting that noise are getting more stringent.

In 2020, new airport noise limits take effect (as part of regulations known as Stage 5 in the U.S. and Chapter 14 globally). Supersonic aircraft currently in development have to comply with those new rules. Aerion already replaced the original Pratt & Whitney engine for its aircraft with the GE engine because of the upcoming regulations. The AS2 is designed to fly at Mach

A rendering of the Spike S-512 supersonic business jet. *Image courtesy of Spike Aerospace.*



43% of *DE* 2018 survey respondents ranked regulatory challenges as an extremely/very important challenge in their day-to-day work.

1.4 over water, but could potentially reach Mach 1.2 over land without its sonic boom reaching the ground.

The rules limiting supersonic travel helped sink the Concorde, but the companies *Digital Engineering* spoke to say they can succeed by designing their aircraft to meet existing standards and by limiting supersonic flight to certain geographies or over water.

"In some cases, rules for supersonic airplanes that cruise at altitudes up to 60,000 feet simply don't exist, and we will work with regulators to come up with solutions that allow progress without compromising safety," says Boom's Dourado. "In light of widespread prohibitions on overland supersonic flight due to the issue of sonic boom, we baseline a subsonic cruise speed over land and a Mach-2.2 supersonic cruise only over water. Even with this constraint, there is a market for nearly 2,000 of our airliners, and hundreds of routes worldwide have enough premium-cabin demand that the aircraft makes economic sense."

"The AS2 requires no regulatory changes to enter service, as it will comply with the latest noise and emissions standards," says Aerion Supersonic's Miller. However, he adds that potential changes at the FAA under the new reauthorization bill could lead to development of even faster jets and more over-land flights.

Hypersonic jets will have to clear additional hurdles. Civil hypersonic flight is likely decades away and flight at speeds above Mach 5 is still extremely inefficient. Costs of operating both supersonic and hypersonic planes will be high.

However, the stars seem to be aligning for commercial supersonic flights in the near term. With the work of NASA and others in reducing the effect of sonic booms, new materials and efforts on the part of companies like Spike, Boom and Aerion to improve the efficiency of these planes (and in some cases to meet existing noise standards), the start of commercial flights, at least over water, is probably just a few years away. Most of the companies featured in this article are aiming to put planes in the air between 2021 and 2022. DE

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

INFO → **Aerion Supersonic:** AerionSupersonic.com

→ **Aerion Technologies:** Aerion-Tech.com

→ **Boeing:** Boeing.com

→ **Boom:** BoomSupersonic.com

→ **GE Aviation:** GEaviation.com

→ **Spike Aerospace:** SpikeAerospace.com

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Break through Barriers with Generative Design

Innovation vs productivity. Design vs manufacturing. Increased competition. Can emerging technology save the day?

TECHNOLOGY THAT improves productivity alone, maybe not. But, technology that enhances our ability to break down silos, share data, and connect design and manufacturing processes - will be a game changer.

For years, design and manufacturing have been working in parallel. When they finally do intersect, it's late in the product development process at which point our ability to make dramatic change is limited by time or cost. Imagine being able to get back all that time wasted on re-work. Imagine having the ability to solve design or engineering challenges with unprecedented insight into manufacturing limitations. When design and manufacturing are linked with data at the center, it is possible.

Autodesk generative design is one technology making the convergence of design and manufacturing a reality. It gives you the power to simultaneously generate multiple CAD-ready solutions based on real-world manufacturing constraints and product performance requirements. Autodesk generative design has both additive and subtractive constraints, and the output is an editable geometry that can be brought back into your CAD system. Generative design can unlock ideas and solutions that you could never imagine and significantly improve your teams' innovation and productivity.

Image courtesy of Autodesk.

While many early adopters came from aerospace and automotive, like Airbus and General Motors, mainstream manufacturers of all scales are now adopting Autodesk generative design. Claudius Peters is using it to re-design concreate manufacturing equipment saving 25% in steel material costs, Penumbra engineering is using it to develop durable and cost-effective, additively manufactured products. Autodesk generative design is available now to help you accelerate innovation, improve product performance and reduce both costs and time to market.

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Simulation Solutions that Address Complexity

Engineering simulation software, built in dialogue with the Industry.

MANY ORGANIZATIONS strive to boost their competitive advantage by using simulation in their product design and development processes. This happens in a landscape of tremendous disruption, where products' structure, variations, and performance requirements are more complex than ever. Progress is being made in the development of new concepts in engineering simulation, which exploit newly available technologies, promising to effectively address today's design engineering challenges.

The evolution of such concepts and the deployment of respective software and processes should be considered effective as solutions to industry's challenges only when they are really relevant to engineering problems. When they fit, they extend and accelerate current processes without adding further complexity. For this reason, BETA delivers software designed and developed in close cooperation with the industry, beyond buzzwords.

In the current environment of intricate product definitions with multiple variants, of large amount of data and metadata, of performance requirements in multiple domains, and of an engineering world operating at a global scale, BETA offers simulation software solutions that tackle complexity and deliver tangible benefits. In partnership and continuous dialogue with the engineering world, BETA delivers a portfolio that is really relevant to the engineers' problems, and enables accelerated performance and quality improvement, from the individual user, up to a corporate level.

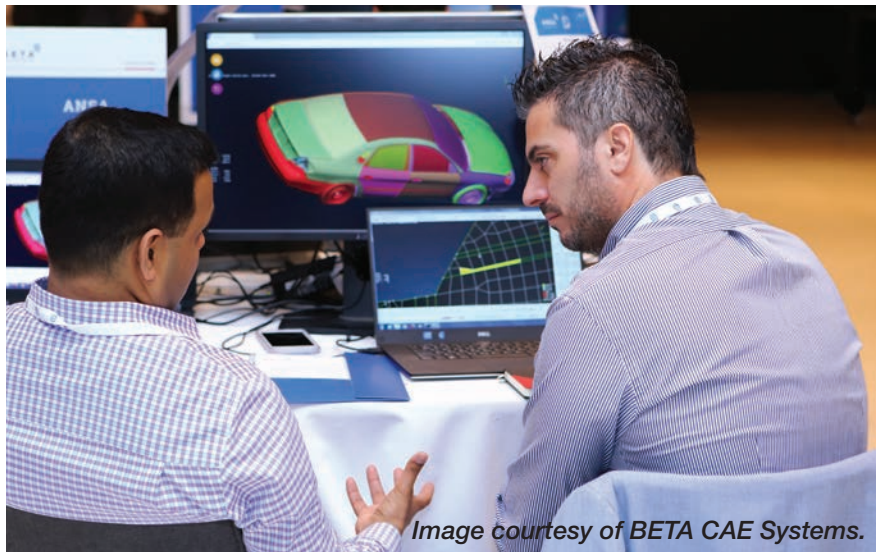

Image courtesy of BETA CAE Systems.

The advanced Simulation Data and Process management with KOMVOS and SPDRM, the versatile and powerful modeling with ANSA, the engagement of the freshly developed solver EPILYSIS, and the high-performance post-processing and visualization with META, have become the trusted core of simulation by the most demanding sectors. Notably, their capabilities for remote collaboration opened new horizons to engineering teams deployed globally. Also, the newly delivered OpDesign enables the optimal product design to be determined in earlier stages.

The portfolio that BETA offers a platform for the engineers to move into the new age of simulation by transforming the way they face their challenges. Because, after all, it is their challenges that drive evolution.

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BETA
SIMULATION SOLUTIONS

Transforming Challenges into Opportunities

As time to market becomes shorter, faster hardware becomes essential.

Image courtesy of BOXX.

AS MOST ENGINEERS and product designers will attest, time to market schedules have become increasingly compressed. Twenty years ago, a product which may have had a schedule of two-and-a-half years from initial design to final product, today may be as short as 15 months. As for the future, one can expect that cycle to be even further abbreviated. This is a difficult challenge to be sure, but it also presents opportunity.

Computer hardware and CAD software are becoming faster, so although competition is fierce (and will continue to be so), with the right tools, a solid design engineering team will be able to keep pace, and even outdistance their competitors.

That's where BOXX comes in. As SOLIDWORKS solution partners and avid users ourselves, we're uniquely qualified to help design engineers custom configure the optimal APEXX workstation to run SOLIDWORKS and other CAD software faster and more efficiently than ever before. Our expertise also stems from the fact that we're not in the business of building standard consumer-grade PCs like our tier-one competitors. BOXX focuses on the professional 3D design and visualization markets, and our strong relationships with software providers and hardware component manufacturers enable us to focus on the future, survey the landscape, and determine ways to improve and support the latest features of your updated software applications.

If you look closely at BOXX customers like Bluewrist, a robotics and machine vision company, or Joshua Raimond, a rocket engineer designer, both profiled in recent customer stories, you'll discover that each had to compete against other design teams—working faster within a shorter time to market while still maintaining the finest in design quality and achieving ROI.

In both instances, challenges became opportunities that resulted in success thanks to good design engineering and purpose-built BOXX solutions.

BOXX

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Collaborate to Innovate with Simulation Applications and Digital Twins

Digital twins, deployed through a centralized resource or as compiled simulation applications, help design engineers shape tomorrow.

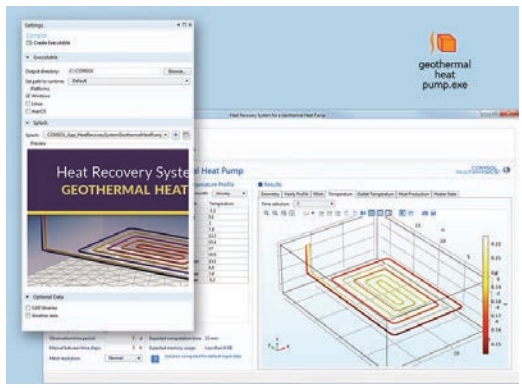
BY BRIANNE CHRISTOPHER, CONTENT MANAGER, COMSOL, INC.

MULTIPHYSICS SOFTWARE is invaluable for simulating designs, devices, and processes in engineering, manufacturing, and scientific research. One of the greatest challenges of incorporating simulation into product development is making it accessible to everyone involved. COMSOL turns this challenge into an opportunity with tools for creating and deploying simulation applications and digital twins.

For simulation to be beneficial to the broader organization, it must be accessible in two distinct ways. First, team members in R&D, manufacturing, laboratory testing, and design should be able to run analyses without relying on simulation experts. The Application Builder, available in the COMSOL Multiphysics® software, makes this possible. Applications provide all collaborators with the capability to perform simulations, avoiding bottlenecks in the development process.

Simulation should also be accessible in the field so engineers can run real-time analyses onsite. This is possible by deploying applications through COMSOL Server™ and COMSOL Compiler™. COMSOL Server™ provides centralized access to simulation for specialists, design teams, R&D teams, and more. COMSOL Compiler™ makes simulation accessible in an even broader sense. Simulation engineers can use this new product to compile applications into standalone executable files that can be deployed to anyone, anywhere. Application users can open a compiled application and run their own simulations without a COMSOL® license or internet connection.

Industry engineers and researchers are already accelerating product development by building numerical simulation applications and distributing them throughout their organizations. For example, one materials science company uses COMSOL Server™ to deploy applications to the right contributors at the right time, helping their teams collaborate in the development of innovative products.



The heat recovery system geothermal heat pump application, with custom icon and splash screen, shown as an executable file after clicking the Create Executable button in the Compiler Settings window. *Image courtesy of COMSOL.*

Widespread access to simulation applications and digital twins allows design engineering teams to tap into their greatest asset: each other.

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Multi-fidelity **Optimization** with Cloud Services

Multi-fidelity optimization saves time and cost, while maintaining accuracy.

OPTIMIZATION DRIVEN design allows an efficient exploration of the design space to improve existing solutions, as well as identify options that would have not emerged with a traditional approach. The quest for the perfect design requires large numbers of analyses of objectives and constraints escalating the level of precision of models.

However, including higher-fidelity analyses in the design process increases complexity and computational expense, and can be quite time and resources intensive.

The use of analytical models can minimize the expenses of high-fidelity ones at reduced computational cost and ultimately speed up the solution of an optimization problem. Two models of the same physical system with different fidelity can be created: one accurate and expensive and one less costly but less precise.

Multi-fidelity optimization provides a mean to leverage both low- and high-fidelity data in order to minimize the cost of the parametrization while maximizing the accuracy of estimates.

With VOLTA, the ESTECO web platform for multidisciplinary business process optimization and simulation data management, multi-fidelity optimization is taken to a new level with the use of cloud services.

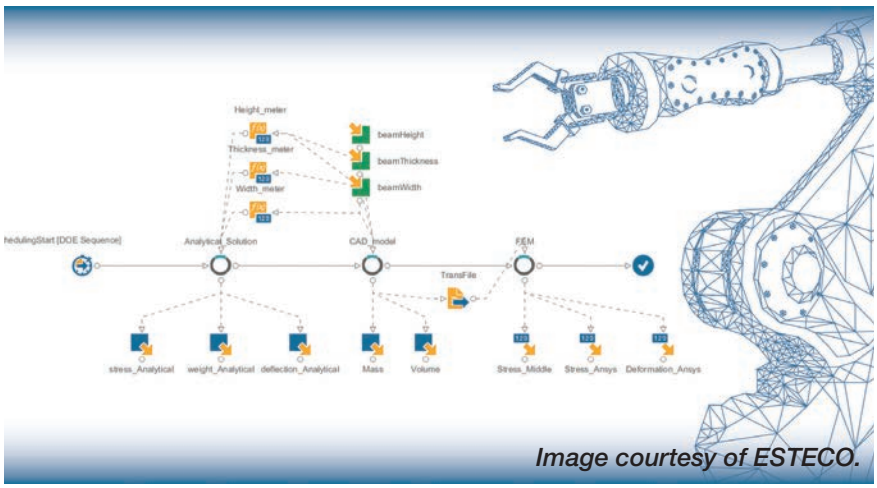

Image courtesy of ESTECO.

As an example, let's think of a 3D FEM simulation, used by engineers to get true insights into a structure design to prevent possible structural failures.

The structure is evaluated using a Google Sheet (spreadsheet) to get a first analytic estimation of the deflection and stress—our low-fidelity model. The low-fidelity model filters out unqualified designs and skips the high-fidelity model run. When the prediction of low fidelity models is promising, VOLTA generates model geometry by updating the model in OnShape or other Saas CAD software. The result is connected seamlessly via VOLTA in ANSYS Workbench for the 3D FEM simulation—the high-fidelity model. At this stage, stresses and deflections are computed. VOLTA drives the multi-fidelity optimization and facilitates the design choice, all on cloud services.

Engineers can choose the most appropriate VOLTA optimization strategy, where all ESTECO best-in-class algorithms are available, to analyze the best design. Computational resources and time-to-market are minimized while product quality remains high.

The use of ESTECO web technologies and cloud services give innovative companies access to new means of reducing development costs and time, without compromising the outcome of the engineering design process, essential to be competitive in today's fast-paced market.

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Capture, Measure, Analyze

Ensure quality while connecting product design and manufacturing.

IN TODAY'S FAST-PACED, digitized product development and manufacturing environment, product designs are more complex than ever and lead times are shorter, a combination that threatens to derail digitization efforts and quality control. Engineers need precise tools to bring physical measurements into their digital workflows.

With more than 30 years of experience, FARO® is the world's most trusted source for 3D measurement, imaging and realization technology. The U.S.-headquartered company, with offices worldwide, develops and markets computer-aided measurement and imaging devices and software for the following vertical markets:

- Factory Metrology
- 3D Design
- Construction BIM
- Public Safety Forensics

Design and test engineers can use FARO solutions to capture detailed and precise 3D data from existing products, permitting CAD analysis and redesign, as well as aftermarket design and legacy part replication. Their counterparts on the factory floor can rely on FARO for high-precision 3D measurement, imaging and comparison of parts and complex structures within production and quality assurance processes.

The FARO 8-Axis Design ScanArm solution with the new FARO PRIZM Color Laser Line Probe provides extended reach with minimal effort.
Images courtesy of FARO.

Continuous Innovation

In 2015, FARO disrupted the large CMM market with the Super 6DoF TrackArm solution that integrated the FARO Vantage tracker and the FaroArm®. It is capable of measuring or scanning over tens of meters with no loss in accuracy, no line of sight issues and simultaneous measurement by many operators.

This year, FARO introduced the 6Probe, a fully integrated hand-held probe for easily probing hidden, hard-to-reach features in hard-to-reach locations. This new functionality addresses a wide range of large-scale metrology applications across a variety of manufacturing focused industries.

FARO also broke new ground this year with the first arm-based solution to include high resolution, 3D color scanning capability. The FARO Design ScanArm® 2.5C enables parts and objects to be reconstructed and visualized as vividly as they appear in the real world. It allows design professionals to proceed with an even higher level of confidence and accelerates the completion of important projects.

FARO continues to expand its leadership as illustrated by its recent acquisition of Open Technologies, which offers a suite of products that reduce time and effort for product design, reverse engineering, dimensional measurement as well as medical and dental.

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FARO®
3D VISIONARY

Rethinking Design Data Management

Onshape is the only CAD system with built-in version control at its core.

BY JON HIRSCHTICK, CEO AND CO-FOUNDER, ONSHAPE

WHY ARE SOME of the best engineers asking where the latest version of their work is? Because usually CAD data is edited by multiple people in multiple places.

When designing products in traditional CAD systems, you need to manage tons of files — especially with large assemblies. You save a version, make some changes and rename the file. Copies are emailed to colleagues and get copied everywhere. There's never really a way to know if you truly have the latest version.

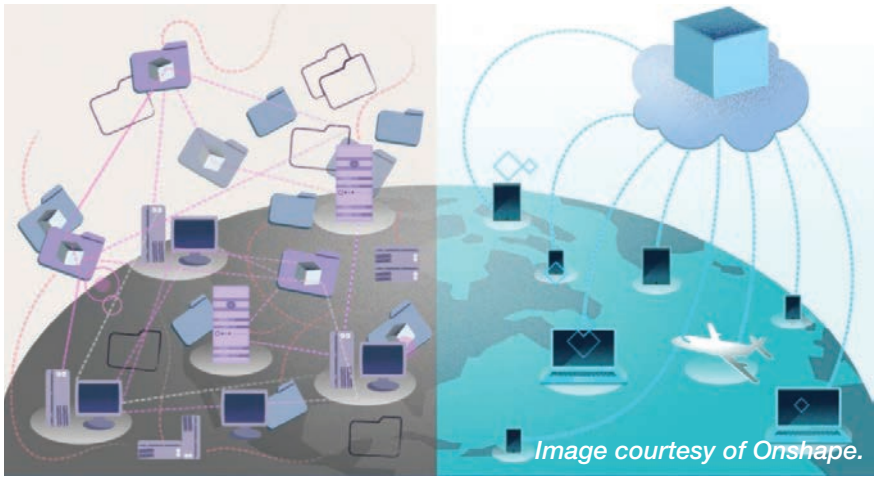

Image courtesy of Onshape.

If you're using traditional file-based CAD, your world likely looks like the left-hand side of the picture on this page. At best, this chaos and confusion can lead to lots of wasted time and rework. At worst, the wrong parts get manufactured.

With Onshape's modern cloud CAD, it's easy to find the latest version because there's only one place to look for it.

Onshape has no files. Because your CAD data is stored in one central database in the cloud, it updates in real time as your team members edit. When anyone makes a change to your 3D model, everyone instantly sees it. And a comprehensive edit history records who did what and when, allowing you to instantly revert back to any stage of your design.

Onshape customer Azizi Tucker, CTO of XING Mobility, oversees three teams of engineers designing complex battery assemblies (7,000+ components) for electric vehicles. "With our previous CAD system, we used to spend about 50% of our design time on file management," he says. "With Onshape, that's history."

Onshape's real-time data management also eliminates the need for expensive PDM system servers, installs, licenses or backups. At last, the "Where's the Latest Version?" problem is no longer a problem.

Onshape

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Simulation and Test Solutions for the Holistic Digital Twin

Engineer your innovations with Simcenter™.

CONSUMERS TODAY want smart products, tailored to personal needs, preferences and habits. To satisfy these needs, manufacturers have to come up with increasingly complex designs that combine mechanics with electronics, software and controls.

To be successful, traditional verification and validation process will need to evolve into a more predictive approach that truly drives innovative product development and closes the loop with the product in use.

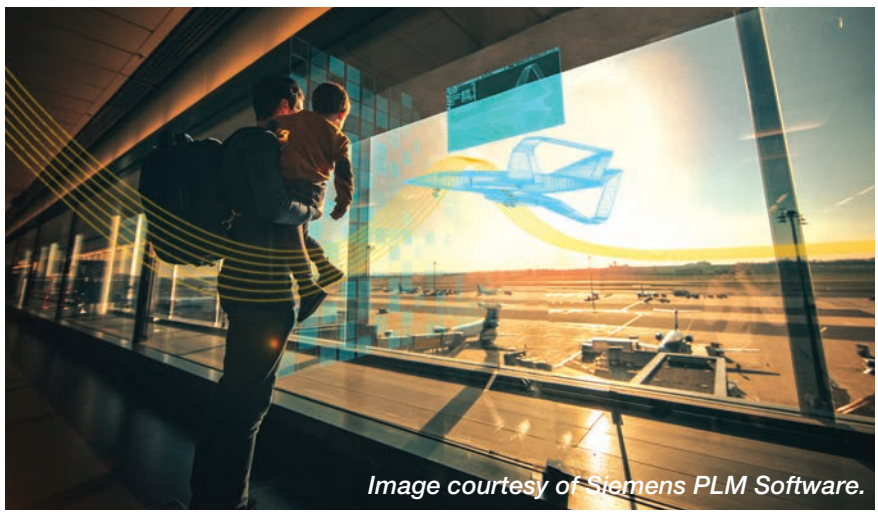

Image courtesy of Siemens PLM Software.

Simcenter. Engineer innovation.

Forward looking companies across different industries are leveraging digital twins to speed up product development. Siemens PLM Software provides solutions that help our customers build, manage, and utilize holistic digital twins, spanning activities in product design, manufacturing, and in-service performance.

The Simcenter portfolio uniquely combines systems simulation, 3D computer-aided engineering (CAE), and test to help you build digital twins that predict product performance across all critical attributes.

These digital twins have the realism necessary to capture the complexities arising from different types of physics—such as structural, thermal, flow, motion, electromagnetic, and multiphysics scenarios. Simcenter includes solutions that enable design space exploration and analytics to help you create better designs faster.

Connect the Digital Thread

Simcenter integrates seamlessly with other solutions to create a digital thread that enables companies to maintain full traceability and close the loop from requirements to actual performance.

Optimize Faster

Simcenter engineering and consulting services are offered to help you solve the toughest engineering problems and accelerate product design and development.

By combining physics-based simulations with deep insights gained from data analytics, Siemens Simcenter helps you optimize your product and system designs to engineer breakthrough innovations faster and with greater confidence.

Learn more about Simcenter at siemens.com/Simcenter.

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SIEMENS

Exoskeletons on the Move

Sensors, CAD models and human-based designs advance wearable exoskeletons.

BY TOM KEVAN

WEARABLE DEVICES bestow incredible abilities, enable warehouse workers to lift great weights, gain extraordinary endurance and allow the disabled to recover some of their lost capabilities. These devices, called exoskeletons (exos) work with the user, augmenting, reinforcing and restoring human performance. Exos can consist of rigid materials, like steel, and soft parts such as elastic fabric. These devices can be active—powered by actuators and batteries—or passive, they can be mobile or stationary, and cover the entire body or just a single body segment.

The relationship between exos and the human body—with all of the operating variables and the need for seamless interplay—poses great challenges for design engineers. Additional complexities compound these difficulties, forcing development teams to face issues like usability, affordability and design flexibility.

Just Getting Started

These challenges are, to an extent, simply reflections of the technology's evolution. Exos represent different things to different users and industries, and the technology's complexity precludes a single clear definition. The fact is that exokeleton technology is continuously evolving and reinventing itself.

Once considered just a novelty, exoskeletons have started to demonstrate their practical value. According to the ABI Research report, "Robotic Exoskeletons: Classes, Markets, and Applications (bit.ly/2qL2ypx), as of 2018, global exo shipments will be at 7,000 units. The research firm, however, expects total shipments to exceed 91,000 by 2023 and reach 301,000 by 2028.

ABOVE: An upper-body exoskeleton that elevates and supports a worker's arms to assist them with chest-height and overhead tasks, the EksoVest is made of lightweight materials, including carbon fiber mesh and a metal-tube frame. ***Image courtesy of Ekso Bionics.***

Forces Driving Exo Momentum

Many factors are promoting increased exo adoption. For example, startups have significantly enhanced these systems by improving drives, materials and power sub-systems. New battery technology now promises to power exo-suits for as long as eight hours.

Furthermore, overall market conditions are improving. Changes in government policies have created an increasingly friendly regulatory environment. Equally important, the aging workforce and systemic skills shortage in developed countries has put pressure on companies to invest more in their employees, with exos becoming a force-multiplier to improve productivity.

Market analysts predict that exoskeleton systems adoption could save companies billions of dollars by reducing hours lost due to physical injury. A bellwether of the improved atmosphere can be seen in the accelerating rate of deployments

of the technology among large Tier 1 companies and original equipment manufacturers (OEMs), such as Ford Motor Co., which recently rolled out an exoskeleton program for employees in 15 plants and seven countries around the world.

> **"Matching the exoskeleton with a 3D humanoid model revealed the limitations of the software tools available."**
> – Andrea Ivaldi, Comau

Why Not Just Use Robots?

As appealing as these benefits are, in this age of growing automation why deploy exos when you can use robots?

The answer is that the industrial sector isn't ready to take humans out of its operations. Although exos enable humans to more efficiently perform physical tasks in industrial environments, humans provide an ingredient that current machine technology cannot match: agile intelligence. Industrial processes are often just too complex to automate with current systems.

This is where exo technology comes into play. Exos can act as a bridge between the extremes of fully manual, nontechnology-enabled tasks and those processes that demand traditional industrial robots. The exo-human hybrid provides a solution that leverages the intelligence of human operators and the strength, precision and endurance of machines.

Defining Concepts, Problems and Specifications

The development of an exoskeleton differs from the creation of more established products because of the number of undefined elements engineers need to contend with and combine.

"The specification and concept steps are as important for exoskeletons as they often are for any technology/product that is very new and thus has a wide open and unknown design space," says Adam Zoss, staff scientist for Ekso Bionics, the company Ford partnered with on its exoskeleton program.

In developing exos, designers must juggle a variety of what seem like conflicting features. The absence of guidelines and benchmarks makes weighing concepts and specification tradeoffs all the more challenging.

Comfort/Usability vs. Durability/Performance

Although the exo design space seems a jumble of variables, with each product and application demanding its own unique set of requirements, some parameters have almost universal applicability. For example, a major challenge that almost always arises during the exo design process is the need to keep the frame as small and lightweight as possible while still maintaining adequate strength and durability. Because exoskeletons are wearable devices, the smaller and lighter the device, the more comfortable and practical they become.

"We determined through market research that the comfort of the device was critical to the success of the product," says Kevin Dacey, senior mechanical engineer at Ekso Bionics. "At the end of the day, no matter what features we offered through the functionality of the device, if it wasn't comfortable, the end user was not going to wear it throughout their day. A key component to comfort is the actual weight of the exoskeleton."

At the same time, the importance of durability can be seen in the company's experience with its customers. "The end users at Ford Motor Co. lift their arms up to 4,600 times per day while assembling vehicles," says Dacey. "That's over 1 million times per year. Our device [The Ekso Vest] needed to provide reliable durability while exposed to that cycle count over multiple years of use."

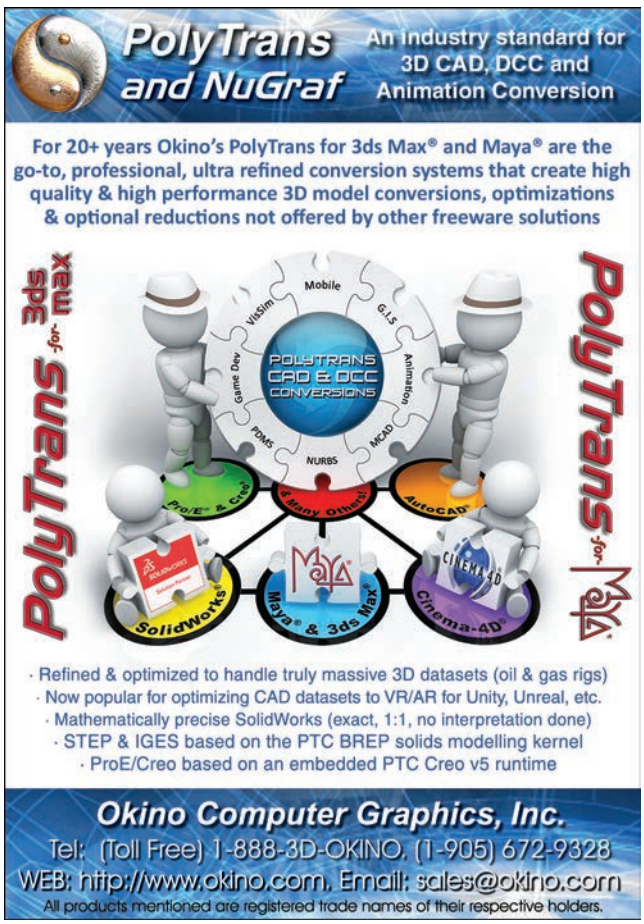
In a related issue, designers must weigh component strength vs. system performance. Here, the designer must determine the optimum strength of actuation and sensing hardware given cost and reliability constraints.

Modularity Provides the Right Fit

Another major challenge arises from the designer's need to meet the demands of potentially mutually exclusive goals. On the one hand, the exo must tightly integrate with the wearer. On the other, the design must have the flexibility to accommodate as broad a spectrum of users as possible.

"One of the most challenging hurdles in developing exoskeletons is how best to design a system that can accommodate a large user population," says Anthony Mickle, senior communications representative at Lockheed Martin, which offers the FORTIS exoskeleton for industrial use and the ONYX exoskeleton for the military. "There is a significant variation in anthropometry, or body type, size and weight."

For practical purposes, exoskeletons are often designed as one



device fits all (or most) through adjustments. The goal is to design the device so that it has the modularity to make "it easy and simple to select the proper size and support level for different users," says Joseph Zawaideh, cofounder and vice president of marketing and business development at Levitate Technologies, which has released a wearable exoskeleton called AIRFRAME.

This is easier said than done, partly because of the shortcomings in tools available to the designer. "Human factor data and tools or human models can help with this aspect, but they fall very short of reaching the level of detail necessary to help with all the challenges associated with designing a wearable device," says Zoss.

Design Tools: Successes and Fails

As with the development of more conventional devices, modeling and simulation play important roles in the design of exos. Development teams use solid modeling CAD and CAE programs to develop engineering drawings, while leveraging ECAD/EDA software to create electronics subsystems.

Later in the design process, designers use various simulation tools to evaluate design functionality, structural strength and dynamic properties. For example, designers extensively use finite element analysis (FEA) software to evaluate the mechanical strength of exo components and to balance the size, weight and strength of the various subsystems. "[FEA] gave us important insights and a boost in performance of the device," says Andrea Ivaldi, product marketing manager at Comau, a subsidiary of Fiat Chrysler Automotive that focuses on industrial automation and has introduced the MATE, Comau Exoskeleton.

Design teams also use mathematical modeling to optimize the mechanical performance and kinetic simulation to evaluate the dynamic properties of the exo's moving parts.

That said, shortcomings in modeling tool functionality hinder handling features unique to exo design, where the challenge is to tightly integrate the exo with the person wearing it. For example, CAD models of people generally scale in the major dimensions, such as height, width and leg length, but they fall short in representing smaller aspects, such as calf size.

Furthermore, these models fail to represent major body shape differences. Creating designs that properly fit every person's body shape, aligns with their joints and attaches in a comfortable manner becomes problematic.

"Matching the exoskeleton with a 3D humanoid model revealed the limitations of the software tools available," says Ivaldi. "The main limitations are the variation of body shapes and the

Walking Restoration

A commercial bionic walking-assistance system, the ReWalk exoskeleton uses powered leg attachments to enable individuals with spinal cord injuries to stand upright, walk and climb stairs. Invented by someone who was paralyzed in an ATV accident, this exoskeleton aims to be more than a rehabilitation system. It promises to provide users with mobility and independence in everyday life, worn all day, whether at work, out in the community or at home.

The ReWalk exoskeleton operates its six moving joints in a manner that mimics the natural human gait. The system moves both ankles with a spring mechanism that drives a footplate, which bears all of the system's weight. Mechanical motors and gears along the side of each leg move the knees and hips. The system supports walking speeds about two-thirds that of most individuals' walking patterns.

The user controls the system via a wrist-mounted remote that detects and enhances the user's movements. Control and power components—including sensors, software, hardware and batteries—are worn around the waist, managing sit-to-stand functions, walking speeds, movement up and down stairs and sit-from-standing functions.

"The basic motor and mechanical designs relied somewhat on configuring known technologies," says Larry Jasinski, CEO of ReWalk Robotics. "The real inventions that enabled a successful design came from software development, battery designs, hardware controls and better sensors."

The developers have taken the ReWalk exoskeleton one step further, expanding the technology's application in the form of a system called ReStore. This exoskeleton targets those who have had a stroke, or suffer from multiple sclerosis or Parkinson's disease. ReStore promises to provide the ability to make real-time adjustments of the forces needed for walking. ReStore is currently in late-stage clinical trials.

Image courtesy of ReWalk Robotics.

Ergonomically designed, Comau's spring-based MATE exoskeleton offers a design that promises to accommodate different body shapes and sizes, with shoulder size, trunk height and waist-belt adjustment systems. *Image courtesy of Comau.*

complexity of movements that the human body is capable of."

The limitations of traditional simulation tools also pose problems. "Respecting the biomechanics of the human body and allowing for the highest freedom of motion for the user is imperative," says Ivaldi. "Unfortunately, simulation tools still offer limited reliability in representing the motion and range of shapes that the human body can have."

To compensate for these limitations, many development teams turn to extensive test campaigns, using end users. This approach relies on an iterative process that goes through several prototyping and testing phases.

"Our team developed sequential updates of the design and tested them using rapid prototyping techniques," says Ivaldi. "Each prototype was tested in the laboratory and in real-world applications. During the test phase, direct feedback regarding the functionality and usability of the device was collected from the end users. This approach ensured integration of the different operators' needs in the final version."

Digital Human Modeling Software Advances

In response to the limitations of traditional design tools, software providers now offer a number of 3D CAD software packages suited to ergonomic simulation. These digital human modeling (DHM) software tools enable models of humans to interact with virtual products and workplaces in a CAD environment.

Today, the market offers a number of software packages suited to ergonomic simulation. For example, Siemens NX Human—based on Tecnomatix Jack technology—allows rapid evaluation of fit, clearance and reach issues without leaving the design environment.

Another example of DHM software is the AnyBody Modeling System, which allows designers to create detailed musculoskeletal models and run computer simulations that integrate the human body into the product design.

Dassault Systèmes also includes DHM tools in its Delmia Ergonomics Specialist product. In this platform, designers can place mannequins into a 3D model to evaluate human interactions with a product or workplace.

A Look at the Bigger Picture

Despite the design challenges, exos are gaining momentum on the shop floor and in other industries. Software vendors have infused design tools with features that promise to help engineers come to grips with emerging ergonomic issues. Developers have boosted modeling and simulation capabilities, enabling designers to develop exoskeletons that begin to meet the price vs. performance sweet spot required to open the door for broader adoption.

Looking beyond the short-term prospects of the technology, how will the proliferation of these devices impact the design of other industrial machines and automation systems? It may be too soon to tell. Exos are only just starting their evolution. Based on the current state of the technology, exos impact the human element on the shop floor more than machinery and systems.

"I actually don't think widespread deployment of exos will have a very significant effect on the design of machinery and systems at all," says Ekso Bionic's Zoss. "The vast majority of exoskeletons these days are not aiming to make people superhuman, but rather make tasks people can do without an exo easier, safer and/or more tolerable. Because the exos aren't allowing people to do things they couldn't before, the way the people will interact with machinery and systems will be the same with or without wearing an exo." DE

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

INFO → **AnyBody Technology:** AnyBodytech.com

→ **Comau:** Comau.com

→ **Dassault Systèmes:** 3DS.com

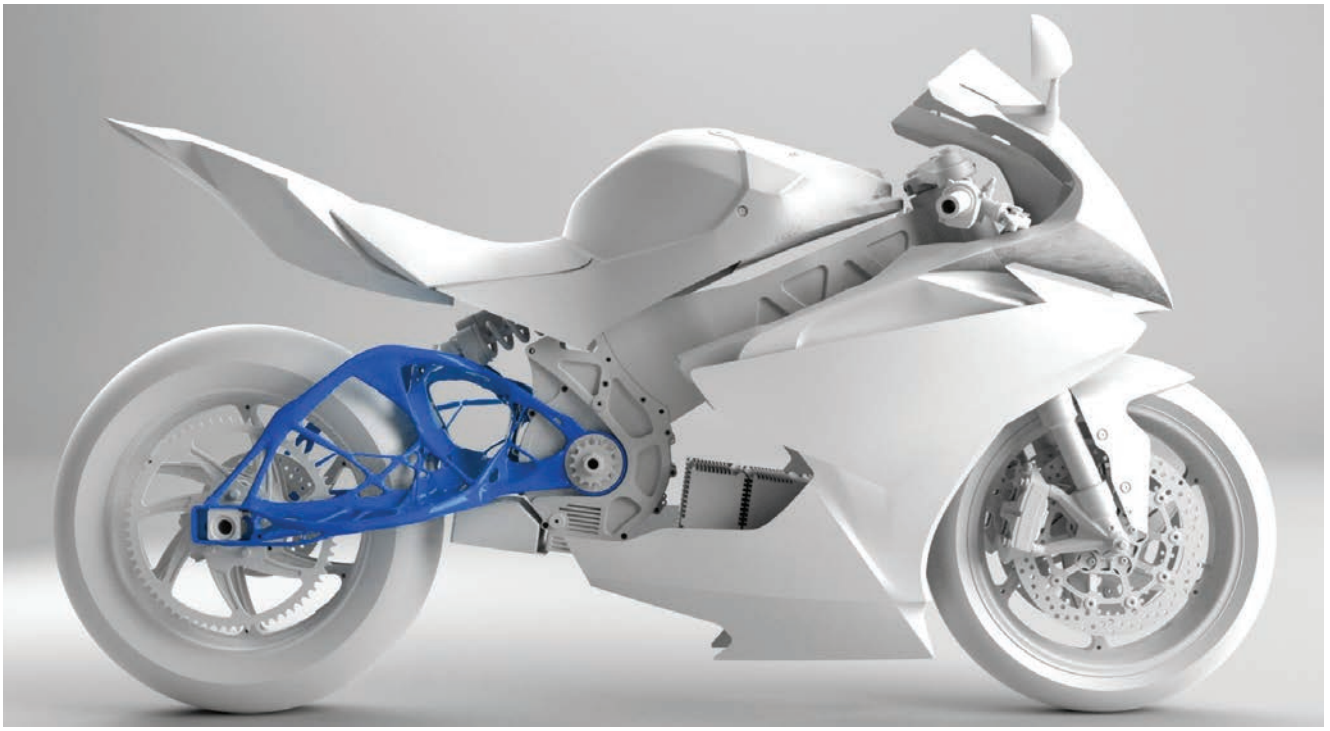
→ **Ekso Bionics:** EksoBionics.com

→ **Levitate Technologies:** Levitatetech.com

→ **Lockheed Martin:** Lockheedmartin.com

→ **ReWalk Robotics:** ReWalk.com

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



Artificial Intelligence Beyond the **Hype**

Advancements in computing and research are making AI applications much more feasible.

BY RANDALL S. NEWTON

IF YOU FREQUENTLY READ TECHNOLOGY NEWS, there's probably not a day that goes by without your reading something alarmist or disparaging about artificial intelligence (AI). Does one of IBM's competitors think Watson is over-hyped? Is a politician worried about job loss? Is there a HAL in our future? Techno-celebrities including Elon Musk and the late Stephen Hawking have offered up various predictions not suitable for bedtime reading.

University of California, Berkeley, researcher Michael I. Jordan divides AI into three categories: 1. imitation, such as portrayed in science fiction; 2. augmentation, when AI and the other disciplines are used to extend and enhance human activity; and 3. connection, where technology intelligently processes massive real-time data streams, as required by autonomous vehicles. Jordan argues people are wasting their time on the imitation stage when there is so much real value to be achieved by using augmentation and connection.

Despite the hand-wringing, engineering software companies are taking Jordan's advice. There is real value being created using AI and its related technologies, machine learning (ML), deep learning (DL) and even computationally intensive generative design (GD). Every major engineering and manufacturing software vendor and several startups are working on intelligent technologies with a wide variety of practical applications that will make boring science fiction but exciting accounting.

Intelligent Algorithms

"There is absolutely hype and excitement surrounding AI [in engineering]," says Rich Rovner, VP of Marketing at MathWorks. "There is more excitement than reality. But we are seeing people doing real design engineering with AI." Some of the most important work today is in creating algorithmic models for engineering. "Data is the key; AI models are amazing but they need pre-processing. Our customers are applying domain-specific algo-

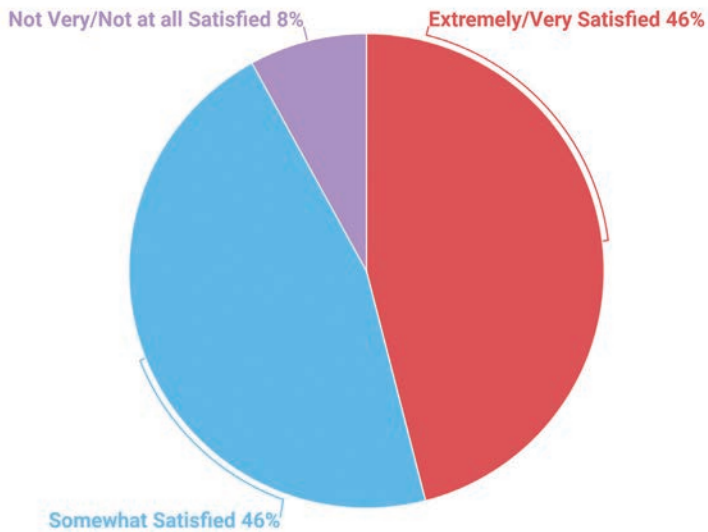
LEFT: Autodesk researchers are studying how artificial intelligence can be used with existing generative design technology. The swingarm (blue) was considered "impossible" to create using traditional design and manufacturing techniques. But an AI algorithm found a way by combining generative design for optimization with 3D printing methods. *Image courtesy of Autodesk.*

rithms to processing their information," he adds.

Such model development often gets folded into larger systems models, Rovner says. Building a predictive model of wind turbine development, for example, requires all the physics and components found in CAD and CAE models. Running simulations on the engineering model can then generate a dataset that an AI algorithm can use. "Use the simulation data to inject parameters into the model, to generate failures into the simulation," Rovner says in the case of a wind turbine application. "At the end of the day, the power of AI comes with the ability to bring it into the engineering workflow."

Rovner sees this early stage of AI in engineering as a time when companies are mostly becoming familiar with the processes. "We are shipping stuff now that will be used more in the days ahead," Rovner says. Engineering teams can get started by creating "ground truths for their models" in such fields as autonomous vehicle guidance systems. One such application is semantic segmentation. Every pixel—yes, every pixel—in a single image from an autonomous vehicle guidance system is labeled to identify the object being depicted. "Then run the entire video through the [AI] software and it labels every frame in the video," Rovner adds.

Generative Design Goals Set and Met



The No. 1 of reason why survey respondents implemented generative design software was to increase the productivity of engineers, analysts and designers. Of those, 92% report being at least somewhat satisfied with their progress toward realizing those productivity benefits.

New Predictive Models

Use cases for AI are easier to create in retail or logistics because they have a constant stream of real-world data coming into the organization, says Fatma Kocer-Poyraz, VP of Engineering Analytics at Altair Engineering. "I tell engineering groups, 'you need data, good data in quantity.' Most people don't realize how difficult it is to get this." While historical data might work, there are too many considerations. "How strict were they in recording it? Do simulation results differ from one version to another?

"Applying machine learning to engineering data is not something that can happen overnight," Kocer-Poyraz says. "It is a long-term commitment. More and more in engineering, machine learning is adding value in engineering knowledge performance indicators. Machine learn-

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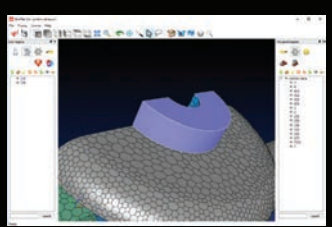

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Altair Engineering is one of several companies involved in using models to generate data for training robots. The virtual robot can be assigned tasks; the deep learning algorithm can then study the robot's movements to help automate future behavior. *Image courtesy of Altair.*

ing means we can automate what the engineer does," she adds, by looking at counter displacements, charts and graphs, and other data to make decisions based on stress and displacement fields.

A machine learning goal can be to train an algorithm to turn stress fields into one number, but "there is no one number to represent the issue or phenomenon; an engineer looks at the entire analysis result. But by working toward this goal, a new predictive model can emerge," says Kocer-Poyraz. This model is one an engineer can use as part of the final analysis.

Altair's recommendations for working with data are echoed by Thomas H. Davenport, author of a new book, "The AI Advantage" (MIT Press, 2018). He offers the following advice on making AI technologies practical:

- use AI to improve processes or products by automating the repetitive or structured aspects of design;
- look for "low-hanging fruit" opportunities to improve efficiency; and
- create smart products that "work alongside smart people."

Smart Generative Design

Generative design is not new to engineering, but it sometimes comes up when the discussion turns to intelligent technology. Most generative design is brute force computation, says Mike Haley, senior director of machine intelligence at Autodesk. But a dataset created from using generative design can be recycled for machine learning applications. "Generative design work is design optimization," Haley notes. If you start with a solid block of aluminum and apply both design optimization and CAE simulation, you have a dataset that can be used for machine learning to guide AI-based decisions about shaping that block into a part.

Haley says Autodesk is researching how to bring intelligent technologies into design using a multidisciplinary approach that mirrors its three markets of manufacturing, construction and media/entertainment content creation. One research effort involves how to bring aesthetics into design. Many manufacturers have a clear style aesthetic associated with their name. "It is a real design language, but hard to measure," Haley says.

When something is hard to measure or quantify, he says, "it becomes a good indicator that machine learning can help. AI software can learn style objectives" if engineers give the algorithms enough data to find commonalities. "It becomes guidance into style instead of shape or weight or other objectives."

AI for CAD Software

nTopology is a young CAD company with a big mission: It wants to replace (or at least supplement) existing feature-based MCAD with an alternative called functional modeling. Founder Bradley Rothenberg says nTopology is using AI in research and development (R&D) to help its software automate the tedious aspects of design. "It is an immense multivariable problem," Rothenberg says. "We allow AI to set up these experiments, to learn what are the important variables. This is a workflow approach, a pipeline." nTopology uses AI iteratively: "There are variables which determine the structure you pick, the material you pick and the algorithms to create the required geometry."

> **"Still the best answer to 'What is artificial intelligence?' remains: 'It is the opposite of natural stupidity.'"**
> – *DE* 2018 Survey Respondent

As with any project using intelligent technologies, data is key. The new CAD software is their initial infrastructure, "but we don't have the data from the field yet," which they need for the "big picture approach to the workflow."

Rothenberg says they are getting data from a variety of sources. One way is to borrow from the idea of a digital thread, where there is a computational pipeline connecting all the parts of engineering. "If a part is going to be built with powder bed fusion, AI can be leveraged to find flaws as it is generated." This is a new avenue for AI research, Rothenberg says. "AI algorithms for computer vision are well advanced, not so much for design." DE

Randall S. Newton *is principal analyst at Consilia Vektor, covering engineering technology. He has been part of the computer graphics industry in a variety of roles since 1985. Contact him at DE-Editors@digitaleng.news.*

INFO → **Altair:** Altair.com

→ **Autodesk:** Autodesk.com

→ **MathWorks:** MathWorks.com

→ **nTopology:** nTopology.com

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Is LARGE-SCALE 3D Printing Sustainable?

Additive manufacturing transitions from prototyping to a means of mass production, raising the stakes for sustainability.

BY KENNETH WONG

WHEN THE EARLY CROPS of commercial 3D printers appeared, they were positioned mainly as prototyping hardware, for creating small numbers of physical mockups and one-of-a-kind models. As such, their output was limited by design, and their environmental impact was negligible.

But over time, the technology evolved and improved in speed and quality. Today, leading automotive, aerospace and consumer goods makers are looking at 3D printing not as a prototyping method but as a means for mass production, in some cases to replace traditional metal-based machining operations. In fact, the term additive manufacturing (AM) has now become just as widely accepted as 3D printing, reflecting the shift in application.

In "Charting the Environmental Dimensions of Additive Manufacturing and 3D Printing," published in the *Journal of Industrial Ecology*, Yale School of Forestry and Environmental Studies, in September 2017, the authors pointed out: "The transition from an industrial prototyping process to a broad range of manufacturing applications creates an urgent need to better understand the environmental effects and impacts of the technology, including those arising from raw materials and energy consumption, distribution, wastes, and health and safety considerations."

Can 3D-Printed Parts be Recycled?

The argument in favor of 3D-printed parts over traditional metal-based parts often goes like this: With 3D printing, you can create parts with complex geometry, porous interiors, lattice structures and membrane structures; therefore, you can create lighter parts with less material, resulting in waste reduction.

But this is a simplistic view that overlooks how materials for 3D printing are obtained and what their long-term effects will be when they become

> **"We have been using 3D printed parts in our products since 2011. It has saved us a lot of time and money."**
> – *DE* 2018 Survey Respondent

Rigid part with lattice interior printed using Carbon's technology. *Image courtesy of Carbon.*

part of hundreds of thousands of everyday items, from electronics, wearables, home decor and furniture to automotive and aerospace parts.

With the two common 3D printing methods—fused filament modeling (FFM) and selective laser sintering (SLS)—nylon, acrylonitrile butadiene styrene (ABS), thermoplastic polyurethane and other thermoplastics serve as the basis for parts. Technically, parts created with such materials can be melted for recycle and reuse.

"Only a handful of plastics are recycled via traditional municipal waste streams, so even if a part is recyclable, it does not guarantee that it will be recycled. Consideration needs to be given to the entire workflow of recycling, including collection, sorting and processing," says Jason Rolland, vice president of Materials at Carbon.

Another 3D printing method, known as UV curing (bonding materials by exposing them to ultraviolet lights) uses thermosetting photopolymers. According to the article "Reprocessable thermosets for sustainable three-dimensional printing," published in *Nature Communications*, in May 2018, UV-cured parts are popular due to "their superior mechanical stability at high temperatures, excellent chemical resistance as well as good compatibility with high-resolution 3D printing technologies. However, once these thermosetting photopolymers form 3D parts ... [they] cannot be reprocessed, i.e., reshaped, repaired or recycled."

"[Carbon] has recently developed novel reversible thermoset materials that provide opportunities for melt-processing parts into new forms or even to recover starting material," Rolland says. "We are working with several partners to scale this approach towards more sustainable closed-loop systems." Carbon is pioneering a proprietary technology called Digital Light Synthesis (DLS).

> **"It will be aggressively adopted in all design engineering. The material development to make additive manufacturing a common design element is key."**
>
> – *DE* 2018 Survey Respondent

With the introduction of its own 3D printing hardware line, dubbed Multi Jet Fusion (MJF), HP is expected to become a major player in the AM ecosystem as well.

"Our Multi Jet Fusion printers were created to be circular and sustainable right from the start," says Nate Hurst, HP's chief sustainability and social impact officer. "For example, both of the plastics that are used—PA12 and PA11—can also be recycled, both as a powder and as a printed part. HP's 3D High Reusability PA12, which is developed to allow reuse of surplus powder batch after batch, delivers consistent performance while achieving 80% surplus powder reusability. In addition, we recently released a PA11 material that is a 100% bio-based content polymer derived from the oil of the castor bean. Castor beans are non-GMO, require little irrigation and are naturally pest- and drought-resistant."

Sustainable and Strong

In April 2018, HP announced an initiative called "Reinventing HP with Multi Jet Fusion." The company says it plans to "leverage its own 3D printing technology to lower costs, speed time to market, increase customer satisfaction and improve sustainability." Accordingly, "HP is using Multi Jet Fusion across its print, personal systems and 3D printing business units."

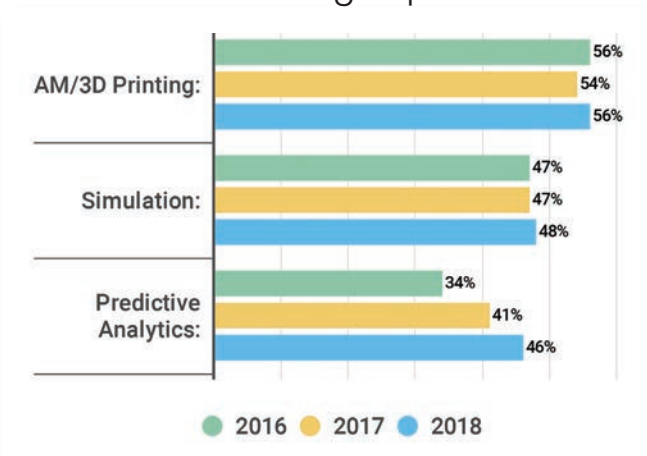
"In some cases, we've been able to replace metals or other plastic alloys, with a single material that will be fully recyclable and overall less mass," Hurst says. "Using 3D printing to make parts for our own HP Latex printers, we have replaced an aluminum part with a 3D-manufactured nylon part, resulting in a 93% decrease in weight, a 95% reduction in GHG [greenhouse gas] emissions and a cost reduction of 50%."

HP isn't the only company to focus on removing mass from products. "The auto industry has proven over the past several decades that metal parts can be replaced with lightweight, durable and cost-effective polymeric parts," Rolland points out.

Traditional metal parts and 3D-printed plastic parts are intended for different applications; therefore, comparing a 3D-printed plastic part to a machined metal part is not appropriate. Comparing 3D-printed plastic parts and traditional injection-molded plastic parts may be more appropriate.

"In the case of Carbon's resins, our materials are already used in hundreds of production applications where they are

3D Printing Impact



When asked which technologies will have the biggest impact on product design and development over the next five years, 3D printing beat out other technologies three years running. *Source:* DE*'s Technology Outlook survey.*

either replacing a traditional injection-molded material, or they are enabling new parts not possible through traditional manufacturing (often via dematerialization). As we advance our materials, we see a great complement between performance and sustainability. For example, materials that can be melt-processed after use will have properties similar to tough, ductile thermoplastics rather than brittle thermosets," explains Rolland.

With the emergence of more affordable metal-based 3D printing, 3D-printed parts are less restricted to plastics-derived materials. Consequently, the AM sustainability question should be revisited as metal-based 3D printing becomes more widespread.

> **"3D printing will allow us to create items internally rather than outsourcing production."**
> – *DE* 2018 Survey Respondent

The Green Appeal

The footwear maker Adidas is now collaborating with Parley for the Oceans, a coalition of artists, activists and researchers working to protect the ocean's fragile ecosystem. The first outcome was a line of Parley shoes, made from recycled marine plastic waste. Was the footwear merchant motivated by a genuine desire to contribute to the growing sustainable movement? Was the plan to generate goodwill for the brand for economic gains? Most likely a mixture of both, but such movements shape the strategies of technology suppliers. One of Adidas' 3D printing suppliers happens to be Carbon.

"Carbon has major sustainability efforts underway in several of our highest volume programs, including footwear and dental. In both of these areas, customer demand for sustainability has helped shape our approach to innovation," says Rolland. "Because we are still very early in the digital manufacturing revolution, we have the opportunity to build in sustainability from the ground up using new approaches in chemistry, hardware, software and post-processing."

"Looking at the industry today, most of the technologically advanced companies who are often the quickest to adopt 3D printing are also the most outspoken in terms of preserving the environment," Hurst says.

In April 2017, HP announced its Open Materials platform initiative to attract third-party vendors to develop materials for HP printers. It comes in the form of a 3D printing material development kit, to simplify testing and certification.

"Since its inception, HP's Open Materials program has not only been focused on accelerating materials innovation, but on collaborating to develop breakthrough new materials that are bio-based, reusable and recyclable," says Hurst. "This is all a part of our commitment to transform our

High-Quality 3D Printing with Recycled Polystyrene

In 2014, a Department of Energy Solar Decathlon competition at the University of California, Irvine (UCI), focused on the design and construction of a solar-powered house. Undergraduates Will Amos and Aldrin Lupisan, UCI environmental engineering students, had been put in charge of the project's "Tool Room of the Future," which featured a 3D printer. "We postulated that each family would be able to recycle their plastic waste into filament for 3D printing so they wouldn't have to buy virgin materials," Amos explains.

Closed Loop Plastics is recycling various post-consumer plastics into high-quality filament for 3D printing. ***Image courtesy of Closed Loop Plastics.***

Sourcing the printer's materials led to an aha moment: What about taking post-consumer plastic waste and turning it into high-quality, engineering-grade materials for 3D printing and other advanced manufacturing processes?

Two years later, the two students and their team continued work turning recycled plastic into 3D printing filament as a senior capstone research project. Now graduated, the pair—along with Sharon To and Jesse Jackson—founded Closed Loop Plastics (CLP; closedloopplastics.com) with the mission, "to advocate benevolent stewardship for the environment, foster environmentally conscious minds, and lower the barrier to entry to sustainable living and design."

CLP currently operates a Prusa i3 MK3, Ultimaker 2+, Ultimaker 3, Rostock Max v3 and Lulzbot TAZ to help it evaluate different plastic blends, printing parameters and final properties. An improved industrial granulator system lets the team input scrap material in almost any form. They are in search of funding to increase their production capacity from kilograms per month to tons per month and have been expanding the business through projects with end user partners such as Sustainable Surf (sustainablesurf.org).

Several months ago, CLP put out a call on social media for individuals to test its PS filament (now verified as true high-impact polystyrene [HIPS]), offering a free 0.25 kg spool in return for survey feedback. *DE* informally put Party Pink to the test.

Read more: digitalengineering247.com/r/21759

Closing the 3D Printing Loop

University of California, Berkeley, Mechanical Engineering Student Nicole Panditi and Environmental Sciences Major Scott Silva have come up with a potential solution to the 600 lbs. of trash the campus' 100 3D printers contribute to each year. Working through the Student Environmental Resource Center, Silva, Panditi and Ph.D. Student Michel Clemon have launched the 3D Printer Filament Reclamation Project. They are creating a system that grinds up and melts printer plastic to make new spools of filament that can then be reused in campus printers.

The students have been advised by Cal Zero Waste, the recycling operation at Berkeley. "The idea is that the plastics would never have to leave campus," says Cal Zero's Manager Lin King. "We would provide Berkeley-produced recycled filament and any discarded items would be sent right back to us."

Read more: digitalengineering247.com/r/21636

UC Berkeley students Scott Silva and Nicole Panditi have developed a closed-loop recycling program for 3D printer filament. ***Image courtesy of UC Berkeley.***

entire business, and those of our customers and partners, to drive a more efficient, circular and low-carbon economy."

The researchers behind Yale's study "Charting the Environmental Dimensions of Additive Manufacturing and 3D Printing," write that their study indicates, "In terms of the environmental impact of the AM process itself [....] the impact of raw materials may be significant" and that "the results of the environmental assessments are sensitive to operating parameters."

As promising as the current initiatives are, more advocacy and coordinated education by industry leaders may be necessary, as businesses' immediate economic concerns may trump long-term sustainable needs.

"Recycling and reuse in the AM industry is certainly of interest among some, but it is largely ignored by most, unfortunately. I suppose companies feel they have bigger fish to fry," remarks Terry Wohlers, president and principal consultant at Wohlers Associates. DE

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

INFO ➜ **Carbon:** Carbon3d.com

➜ **HP 3D Printing:** www8.hp.com/us/en/printers/3d-printers.html

➜ **Parley:** Parley.tv

➜ **Wohlers Associates:** WohlersAssociates.com

➜ **"Charting the Environmental Dimensions of Additive Manufacturing and 3D Printing," Journal of Industrial Ecology, Yale School of Forestry and Environmental Studies, September 2017:** onlinelibrary.wiley.com/doi/10.1111/jiec.12668

➜ **"Reprocessable thermosets for sustainable three-dimensional printing," Nature Communications, May 2018,** Nature.com/articles/s41467-018-04292-8

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Each week, **Tony Lockwood** *combs through dozens of new products to bring you the ones he thinks will help you do your job better, smarter and faster. Here are Lockwood's most recent musings about the products that have really grabbed his attention.*

EDITOR'S PICKS

NVIDIA Quadro RTX Graphics a Game-Changer

PNY expects to fulfill first partner orders for NVIDIA accelerators now.

PNY Technologies, an authorized channel partner for NVIDIA Quadro GPUs, has told its reseller, distribution and other partners that they can take pre-orders for the Quadro RTX 6000 and RTX 5000. That means engineering workstations equipped with these GPUs will be available soon.

The RTX family offers enhanced manufacturing and scientific visualization, virtual environments, photorealistic real-time rendering and more.

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Multiphysics Modeling and Simulation Get Boost

COMSOL's release offers tools for creating simulation applications.

Modeling gurus can now make executable COMSOL Multiphysics simulation applications and freely distribute them without licensing issues.

Work on simulations that combine the Composite Module's structural mechanics strengths with new layered shell functionality in the Heat Transfer module and the AC/DC electromagnetics module. Also, the AC/DC module has a new parts library with ready-to-use coils and magnetic cores.

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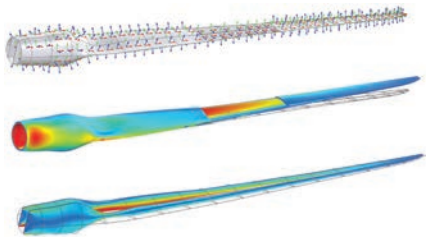

Metal AM System is Configurable and Scalable

EOS expands its DMLS additive manufacturing systems lineup.

M 300 is the designation for this series of Direct Metal Laser Sintering (DMLS) AM systems. They're designed to handle jobs in aerospace, automotive, medical, tooling and more.

The primary characteristic across the series is that it leverages a modular platform that's configurable and scalable for 24/7 production. There are multiple configuration options with two powder dosing options. The series features four lasers with full-field overlap.

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Access Simulation Throughout Design

Altair's new platforms make simulation readily available.

Altair makes available its Altair Inspire simulation-driven design platform and Altair 365, a cloud-based engineering collaboration platform.

Altair Inspire is meant to enable simulation-driven design through the product development process from concept to manufacturing. The Altair 365 engineering collaboration platform is hosted on the Microsoft Azure cloud computing service. It puts you into the realm of scalable high-performance computing and graphics processing.

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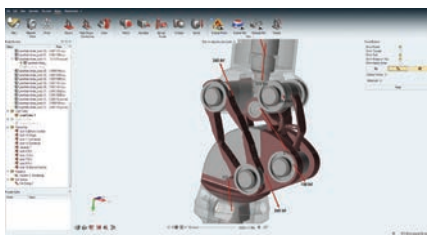

| COMMENTARY |

By Dana Ellis

Manufacturing Industry Vulnerable to Cyberattack

THOSE IN MANUFACTURING already know the industry is among the most targeted sectors for cyberattacks.[1] More than half of the manufacturing plants participating in a recent survey by LNS Research admitted they had experienced at least one cybersecurity breach over the past year.[2]

Although this is nothing new, the industry is becoming increasingly susceptible to such attacks as additive manufacturing (AM) gains wider acceptance, bringing with it a more decentralized approach that allows for companies to manufacture when and where needed. This model certainly has significant benefits, but it also substantially increases the chances for counterfeit, poor quality or uncertified parts to enter the supply chain as ever-increasing amounts of product data travel back and forth between manufacturers, suppliers and subcontractors.

Blockchain Mandate

To maintain the integrity and traceability of the AM digital flow, it is essential to secure supply chain data with blockchain at each phase of the digital supply chain. This begins at the design phase, where design file encryption can ensure that only authorized users have access to the enclosed information. An encrypted digital container should be developed for each part, and prevent access until the design files are decrypted. Access to the data, length of time that it is accessible and how the data should be used can all be defined by the intellectual property owner via a licensing mechanism.

As the next step in the manufacturing process, the parts designer would transmit encrypted design files and a digital license to the downstream users in the digital supply chain, typically through email, an offline system or direct access to the company's server. Again, it's essential to use a smart contract-enabled blockchain here to authenticate, transport and record the digital distribution license. This enables all members of the blockchain to participate, while simultaneously enforcing the distribution and asset management rules set by the smart contract.

From that point on, parts production is typically licensed to multiple manufacturers, each of whom will use the design files to produce parts according to the licensing agreement's digital parameters. Manufacturers will only be able to decrypt the design files once they meet specifications on the equipment make and model, the type of build materials allowed and other parameters. To ensure quality standards and prevent counterfeits from being made on authorized equipment, production rules control the number of parts each manufacturer is licensed to print. All activities should also be tracked and stored on the blockchain ledger to verify the origin of each part and allow any errors to be tracked to their source.

Lastly, each physical part that is manufactured should be tagged with a digital reference and recorded in the blockchain ledger. Coding parts by embedding chemical trackers, radio frequency identification or serialization numbering allows future users to trace any part back to its manufacturer, the machine that created it and the design's original creator. The blockchain ledger can also be used for performance modeling, failure simulation and overall performance improvement of a specific part.

Countering Counterfeits

Overall, blockchain technology is critical for securing the digital supply chain, both as a hedge against lost revenue caused by intellectual property theft and to ensure safety and security. This is particularly true for those manufacturers in the government and military space. A recent Department of Defense (DoD) report noted that equipment no longer made by the original manufacturer typically must be purchased from third-party distributors, opening the door for counterfeit parts to enter the supply chain. Fortunately, AM can help offset this issue by enabling suppliers to store designs and produce the replacement parts on-demand, using the correct design file validated by the blockchain.

Although best practices for securing and authenticating data and improving the digital supply chain through blockchain-enabled security solutions still need to be determined, blockchain technology holds the key to counterfeit mitigation, data integrity, compliance rights and feedback monitoring. Incorporating blockchain into the manufacturing cycle will lead to faster production—accelerating time to market and reducing physical storage requirements—enabling AM to live up to its full potential. DE

Dana Ellis *is senior program manager at the National Center for Manufacturing Sciences (ncms.org).*

Resources

1. bit.ly/2JfRonO
2. bit.ly/2PoFZFT

LS-DYNA® Advanced FEM, Meshfree & Particle Methods

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LS-DYNA® integrates the finite element, meshfree, and particle methods for solving some of the most challenging problems in manufacturing processes, material design, and structural analysis. Such problems typically involve large deformations, material failure, crack propagation, and composite materials. Some of these methods are coupled with the thermal, fluids, and electro-magnetic solvers in LS-DYNA to perform multi-physics analysis as needed.

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- Immersed particle algorithm for composites
- Particle contact for impact problems
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- Shell and solid applications
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- Physics-based failure mechanism
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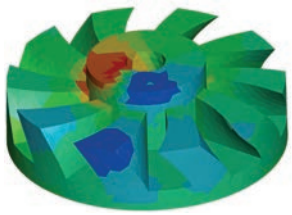
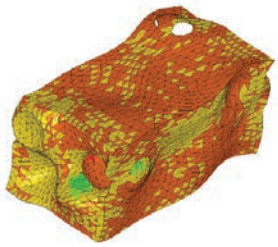
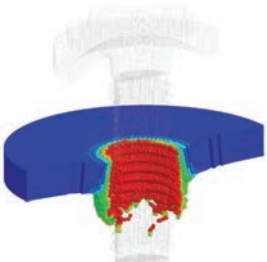
Group Website: www.lstc-cmmg.org



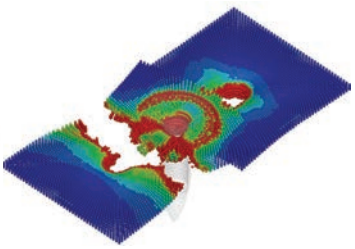
3D printing



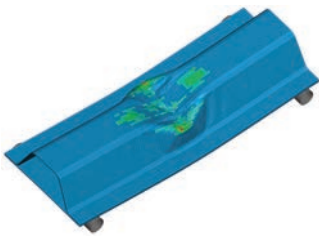
RVE for nano-particle reinforced rubber



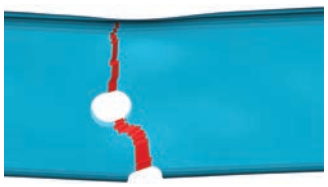
Flow drill screwing (FDS)



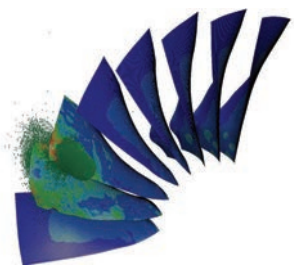
Lap-shear after FDS



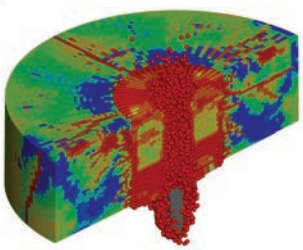
Carbon fiber reinforced polymer



Ductile cracking in shell



Bird strike



Perforation of concrete

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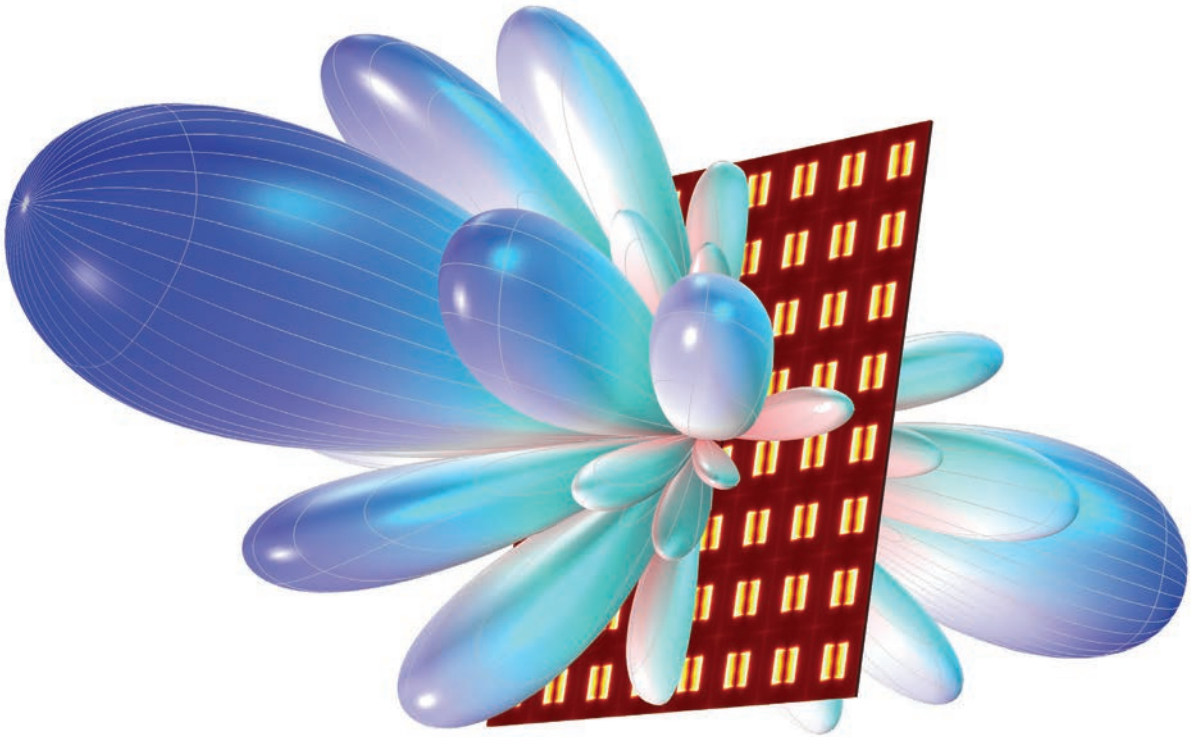
IoT calls for fast communication between sensors.



Visualization of the normalized 3D far-field pattern of a slot-coupled microstrip patch antenna array.

Developing the 5G mobile network may not be the only step to a fully functioning Internet of Things, but it is an important one — and it comes with substantial performance requirements. Simulation ensures optimized designs of 5G-compatible technology, like this phased array antenna.

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