MECHANICAL
ENGINEERING
Technology that moves the world
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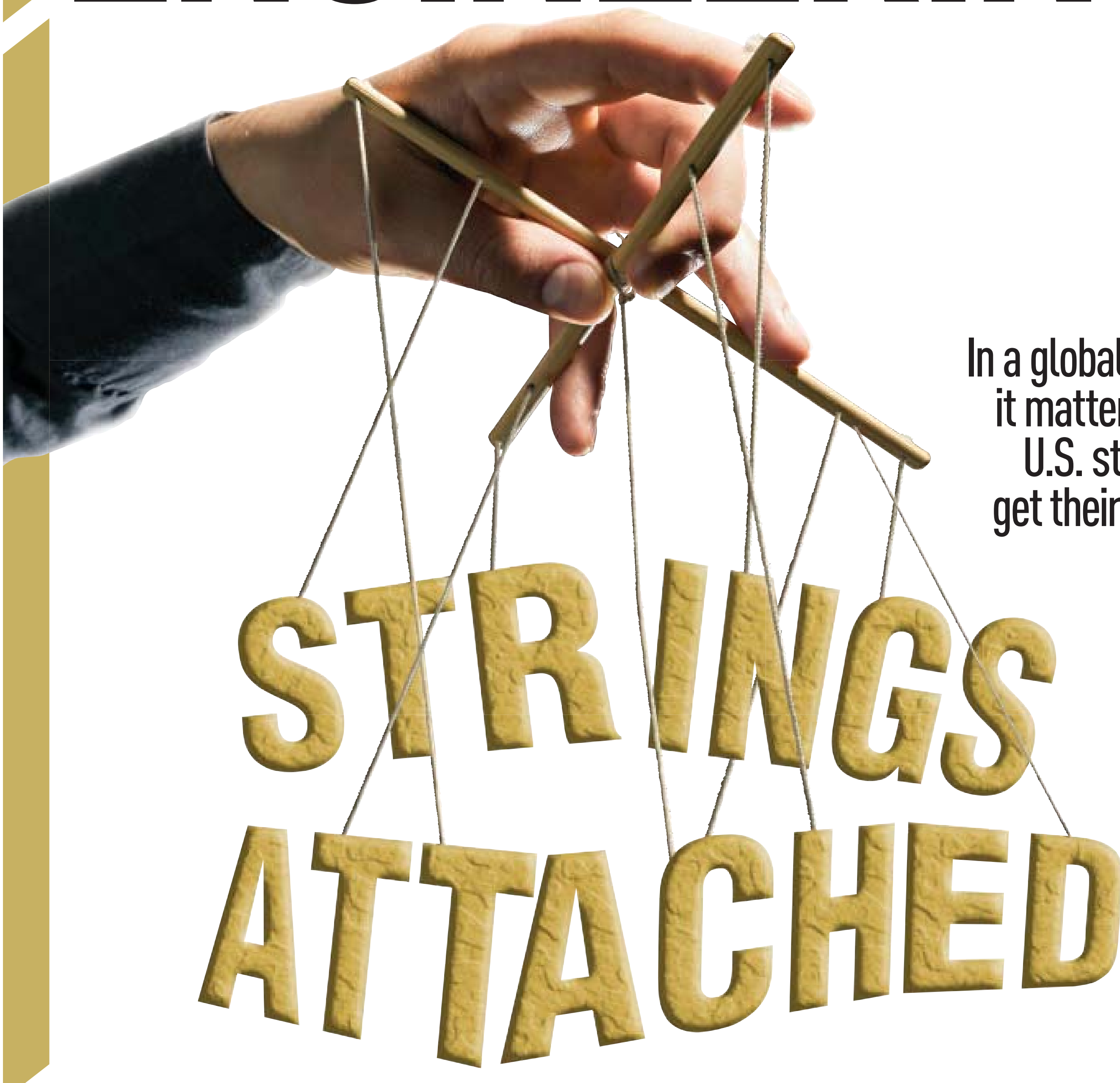

In a global economy, it matters where U.S. startups get their funding.

MANUFACTURING CARS WITH VIRTUAL REALITY

OCULUS RIFT, HTC VIVE, SAMSUNG GEAR, SONY PLAYSTATION VR, Google Daydream View—those funky-looking headsets have become the new frontier for serious gamers. But what once was science fiction is now a reality not only in gaming, but also in automotive manufacturing. Carmakers such as General Motors and Ford are increasingly using VR to ensure their products are evaluated at a very early phase of the design process, thereby reducing the time and cost of developing new models.

BALANCING BOT LEADS THE WAY

CARNEGIE MELLON UNIVERSITY RESEARCHERS have developed SIMbot—a tall, thin helper robot that balances atop a ball. Unlike previous rolling robots, SIMbot's design eliminates the ball's mechanical belts and drives and introduces a spherical induction motor.

For these articles and other content, visit asme.org.

MAGNETICALLY REPELLING ICE

A UNIVERSITY OF HOUSTON TEAM hopes to calm fliers' nerves as well as increase air safety with its "magnetic slippery surface," which is intended to reduce the effects of ice on aircraft wings.

CROWDSOURCING 9-1-1 FOR THE DEVELOPING WORLD

A PARAMEDIC has created a new nonprofit in New York City dedicated to bringing 9-1-1 emergency communications services to the developing world via a text-based mobile platform.

CHALLENGES IN CERTIFICATION FOR ADDITIVE MANUFACTURING

ANDY IMRIE, GLOBAL PRODUCT launch manager for inspection services at Lloyd's Register, talks about the current status of standards for 3-D-printed products and machines.

NEXT MONTH ON ASME.ORG

CIMP-3D ADVANCES DIRECT METAL PRINTING
Learn how the Center for Innovative Materials Processing through Direct Digital Deposition at Pennsylvania State University is advancing and deploying additive manufacturing technology.

AERIAL ROBOT MIMICS BAT IN FLIGHT
Researchers have developed a small, lightweight aerial robot with soft, flapping wings that mimics the complex flight patterns of a bat.

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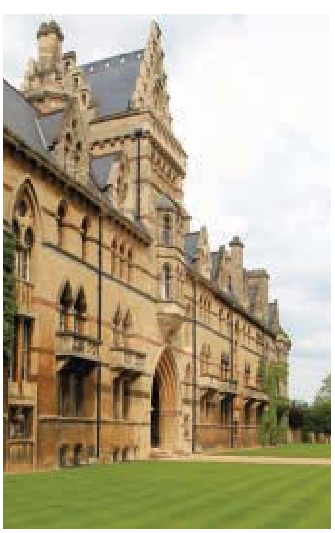

ASME
SETTING THE STANDARD

ORGAN BANKING

Mechanical engineers have the know-how to push back the boundaries of cryopreservation of human tissues.

BY YOED RABIN AND JEDEDIAH LEWIS

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Human-powered art rolls on.

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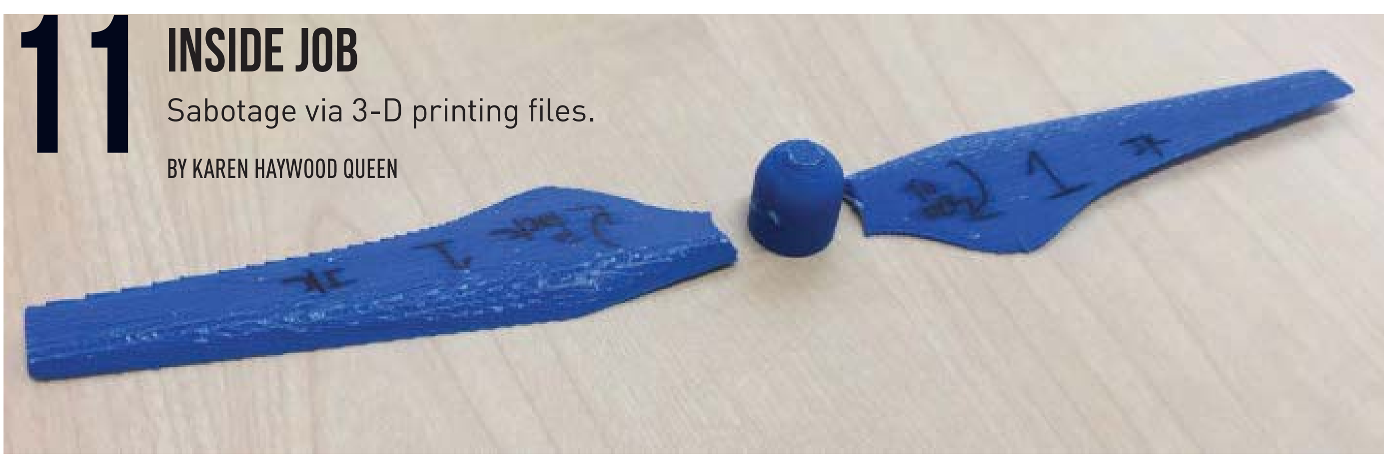

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Give me the place to stand, and I shall move the earth
—Archimedes

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John G. Falcioni
Editor-in-Chief

ADVANCING BIOMEDICAL ENGINEERING

It was wild fantasy back in 1973 to believe we could build a bionic person with artificially enhanced vision and the strength and speed of Steve Austin, the title character of *The Six Million Dollar Man*. According to the TV show, Austin's prosthetic eye could zoom on command and possessed infrared vision. His bionic arm was capable of bending steel bars, and his legs allowed him to chase down (and catch!) speeding vehicles.

Looking back, the biggest fantasy is that we could get all that for just $6 million.

Today, bionics and prosthetics are transforming the real world in ways unimaginable in the '70s. For example, artificial hearts are keeping patients alive until transplants become available; cochlear implants are restoring hearing to the impaired; bionic eyes are beginning to restore sight to the blind; and numerous prosthetic hands, arms, and legs are restoring mobility to thousands around the world.

Alliance of Advanced BioMedical Engineering
POWERED BY ASME

Yet there still are more than 90,000 people waiting for kidney transplants, more than 16,000 waiting for livers, and more than 1,500 waiting for hearts. "The shortage of organs for transplantation is a public health crisis. The gap between the current state of the art and the technology needed for cryopreservation is one that an orchestrated effort between cryobiologists and mechanical engineers can bridge," writes Yoed Rabin, a professor of mechanical and biomedical engineering at Carnegie Mellon University, and Jedediah Lewis, chief executive at the Organ Preservation Alliance.

Their article in this month's issue, "Organ Banking," tells how mechanical engineers are pushing the boundaries of cryopreservation of human tissues. Researchers are tapping heat transfer, solid mechanics, materials science, nanotechnology, computer modeling, and other engineering disciplines to better preserve donated tissues and organs. In August, ASME and the Organ Preservation Alliance are co-organizing a summit in Boston to address those challenges.

Bioengineers and biomedical engineers are broad fields that comprise areas of biology and engineering. The two are amalgams of each other. Biomedical engineers solve medical and biological problems and design health-care technologies, including medical devices and implants, diagnostic procedures and therapeutic approaches. Bioengineers focus on pharmaceutical, medical devices and implants, biotechnology and tissue engineering.

ASME has been involved in these areas for years. The Society's Bioengineering Division, for example, has focused on the application of mechanical engineering principles to the design, development, analysis, and operation of biomechanical systems. The *ASME Journal of Medical Devices* publishes papers focusing on medical devices that improve diagnostic interventional and therapeutic treatments.

Now, ASME has developed the Alliance of Advanced BioMedical Engineering (www.aabme.org), an online content-delivery platform that bridges the gap between research and industry. As the platform grows it will include professional and networking resources aimed at helping engineers be better positioned to work in this burgeoning area.

In sharing industry best practices and trends among life scientists, engineers and medical doctors—as well as by showcasing the advanced work of researchers—AABME will support and advance the industry by helping stakeholders stay on top of emerging technologies. Ultimately, the goal is to positively impact the patients who rely on the expertise of biomedical professionals.

And who knows, this alliance may even help create the first bionic person. ME

FEEDBACK

Visit the Alliance of Advanced BioMedical Engineering (www.aabme.org) and tell me what you think.

falcionij@asme.org

LETTERS & COMMENTS

FEBRUARY 2017

Reader Bublitz suggests that our analyses take worker interest into account.

« Two readers draw differing conclusions to an article. And another reader suggests our take on the President is naïve.

POWER AND THE PEOPLE

To the Editor: The February 2017 issue had several excellent articles on electric power generation, ranging from coal to nuclear to waste-to-energy.

As a business owner and former OEM general manager, I also endorse the message of the Workforce Development column: "People Before Profit."

Great job by you and your staff.

Ron Natole, *LaPorte, Tex.*

COAL IS CATASTROPHIC

To the Editor: The new waste-to-energy plant now operating in Palm Beach, Fla., featured in "Clean Power from Burning Trash" (John B. Kitto, Jr., and Larry A. Hiner, February 2017) sounds like a very impressive facility. It has greatly reduced greenhouse gas production and water use relative to earlier systems and also emits very low levels of dioxins and furans.

In contrast, the Trending in the same issue ("By the Numbers: Can Coal Come Back?" by Jeffrey Winters) was disappointing. In that article, Winters never mentions climate change or the carbon footprint of coal-fired power plants.

I certainly agree that the loss of coal mining jobs has hit Appalachia hard, and that the state and federal governments should be doing far more to help retrain the workers and provide them with other employment opportunities. But that is no reason to pretend that it would be a good idea to expand the use of coal in energy production.

In that article, Winters floats the idea of "scaling back U.S. nuclear power... and making up the difference with coal," though he said he was concerned about "catastrophic effects" on the nuclear industry.

But he makes no mention of the catastrophic effects that increased coal usage would have on our future climate. I can't understand how *Mechanical Engineering* magazine can publish an article on burning coal to produce energy without discussing the huge carbon footprint that coal burning produces.

As a science and engineering society, I certainly hope that the ASME accepts the scientific facts of human-caused climate change, and acknowledges the fact that coal-burning produces 25 percent of U.S. global warming emissions, and 80 percent of carbon emissions produced by power generation nationwide.

Joel Jensen, *Redwood City, Calif.*

SAY IT TO THEIR FACES

To the Editor: In regards to the February 2016 Trending, how about we take the jack-boot of regulation off the neck of the companies that employ the few workers left in the industry and see if they can eke out a living until they die?

Would the the author, Jeffrey Winters, have the courage to deliver the same message to a town hall in West Virginia? I doubt it.

Mark Bublitz, *La Porte, Ind.*

VOTE OF NO CONFIDENCE

To the Editor: I find your confidence in the Trump administration's dedication to the future of NASA's space program (From the Editor, January 2017) to be a bit naïve.

Then-candidate Trump's statement that NASA should be focused on the exploration of the entire solar system is actually a message to his base that NASA should stop working on Earth-centered projects that may create information supporting anthropogenic global warming.

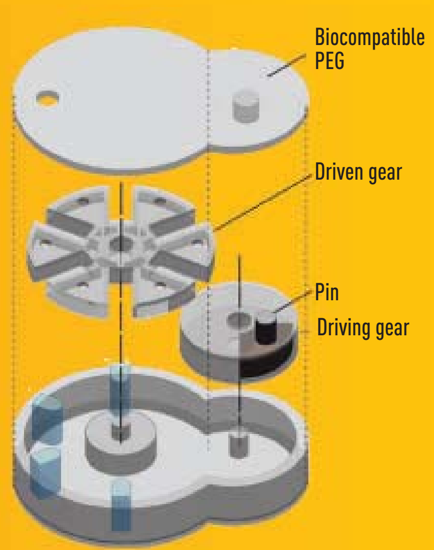
His call for "human exploration ... by the end of this century" seems to emphasize manned missions, but over such a long timeframe that short-term funding for the agency could be at risk.

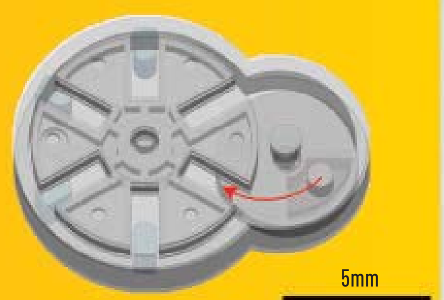
I sincerely doubt that the science community will fare well over Trump's time in office.

Stuart C. Clark, *Sunrise Beach, Mo.*

FEEDBACK Send us your letters and comments via hard copy or e-mail: memag@asme.org (subject line "Letters and Comments"). Please include full name, address and phone number. We reserve the right to edit for clarity, style, and length. We regret that unpublished letters cannot be acknowledged or returned.

MEMS ON THE INSIDE





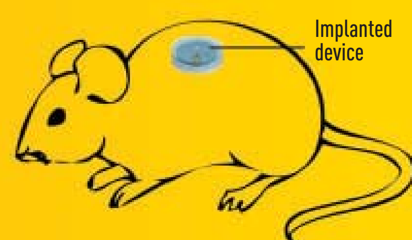
MINIATURE MACHINES MADE OF BIOGEL RELEASE DRUGS TO TISSUES ON DEMAND.

Biomedical engineers have built minuscule implantable, biocompatible machines that can be actuated from outside the body.

The gear-like, hydrogel-based devices, which are about the size of a piece of sawdust, have no batteries, but they still delivered targeted doses of a cancer chemotherapy drug inside a mouse, and they could perform other tasks inside the body. There, they can be actuated by touching a magnet to the surface of the skin, a Columbia University team reported recently in *Science Robotics.*

In fabricating the devices, the researchers provided a proof of concept for a platform technology the team calls implantable microelectromechanical systems, or iMEMS, that could one day also help engineers fabricate tiny biocompatible valves, pumps, manifolds, and rotors.

Biomedical engineers previously have built implantable devices that can be safely implanted into the body to deliver drugs and perform other tasks. But most of them have static components instead of moving parts, and they use toxic batteries that limit their biocompatibility.



Sam Sia, a biomedical engineering professor, sought to overcome those problems by creating biocompatible MEMS with freely moving parts that didn't require batteries. He also wanted to develop a platform for the fast, consistent, and accurate fabrication of micromachine parts.

"Working through the kinks took time because working with soft, squishy materials is a lot different than working with metals," Sia said.

Sia's team creates microscake replicas of the Geneva mechanism, which a Swiss watchmaker invented around the late 17th century to limit the tension of a watch's mainspring. In the four centuries since then, variants of the mechanism—including the Geneva drive or stop, and stepper motor—have helped direct the precise movement of parts in movie projectors, plotters, lathes, drills, and CNC machines.

The researchers' microdrive works exactly like the larger versions, but it's made from hydrogel rather than metal, and it measures 5 mm high and 15 mm at its longest point.

Its parts can be scaled down to about 10 microns, Sia said.

Like the original Geneva drive, this device is made up of a drive wheel with a pin near its outer edge and a driven wheel with several open slots.

The drive wheel includes pie-shaped receptacles containing the drug, which is passively released to the target area through an open window on the side of the wheel.

To actuate the drive wheel, the team doped it with iron oxide nanoparticles, then placed a magnet on the skin of the mouse.

"It moves like a clock and dispenses one dose at a time," Sia said.

In the future, the devices could be used in catheters, pacemakers, and soft robotics.

The researchers built the device in about 30 minutes using their platform technology, Sia said. The platform helps the researchers address some of the main challenges of working with hydrogels (in this case, PEG diacrylate), such as accurately aligning the different layers and fine-tuning the material's stiffness, thickness, and diffusion.

Sia is not sure when the fabrication platform itself will be ready for mainstream use. **ME**

JEFF O'HEIR

3-D PRINTING HACK DOWNS DRONE

This quadcopter uses 3-D-printed rotor blades, making it vulnerable to sabotage.

The 3-D-printed consumer drone hovers in mid-air, as pulsing percussion hints of doom. Then, less than two minutes into its first flight, which was captured on a YouTube video, the drone spins out of control and crashes.

The cause of the crash? The first successful attempt to hack into a computer and sabotage an additive manufacturing design, said researcher Mark Yampolskiy of the University of South Alabama, the coauthor, with researchers from Ben Gurion University and Singapore University of Technology and Design, of a paper on the hack.

The YouTube video, posted in August 2016 and watched by more than 36,000 people so far, could be the Cliff's Notes for a research paper by researchers from Ben Gurion University, the University of South Alabama, and Singapore University of Technology and Design.

Manufacturers are already making parts for jet engine and other machines using additive manufacturing.

Engineers are generally very good at accounting for random natural variations of physical processes," Yampolskiy said, both during manufacturing itself and in real-life conditions a manufactured part will be exposed to.

"These are often accounted for by incorporating a safety factor in the design. Unfortunately, engineers also generally overlook security aspects," he said.

Previous demonstration sabotages of 3-D printing designs started with the perpetrator already inside the computer hosting the design. Then perpetrator simply manipulated blueprints and showed that it could harm mechanical properties, Yampolskiy said.

His team's attack went a step further. They used an ordinary phishing attack, sending an e-mail downloaded an infected zip file. That gave the researchers what they

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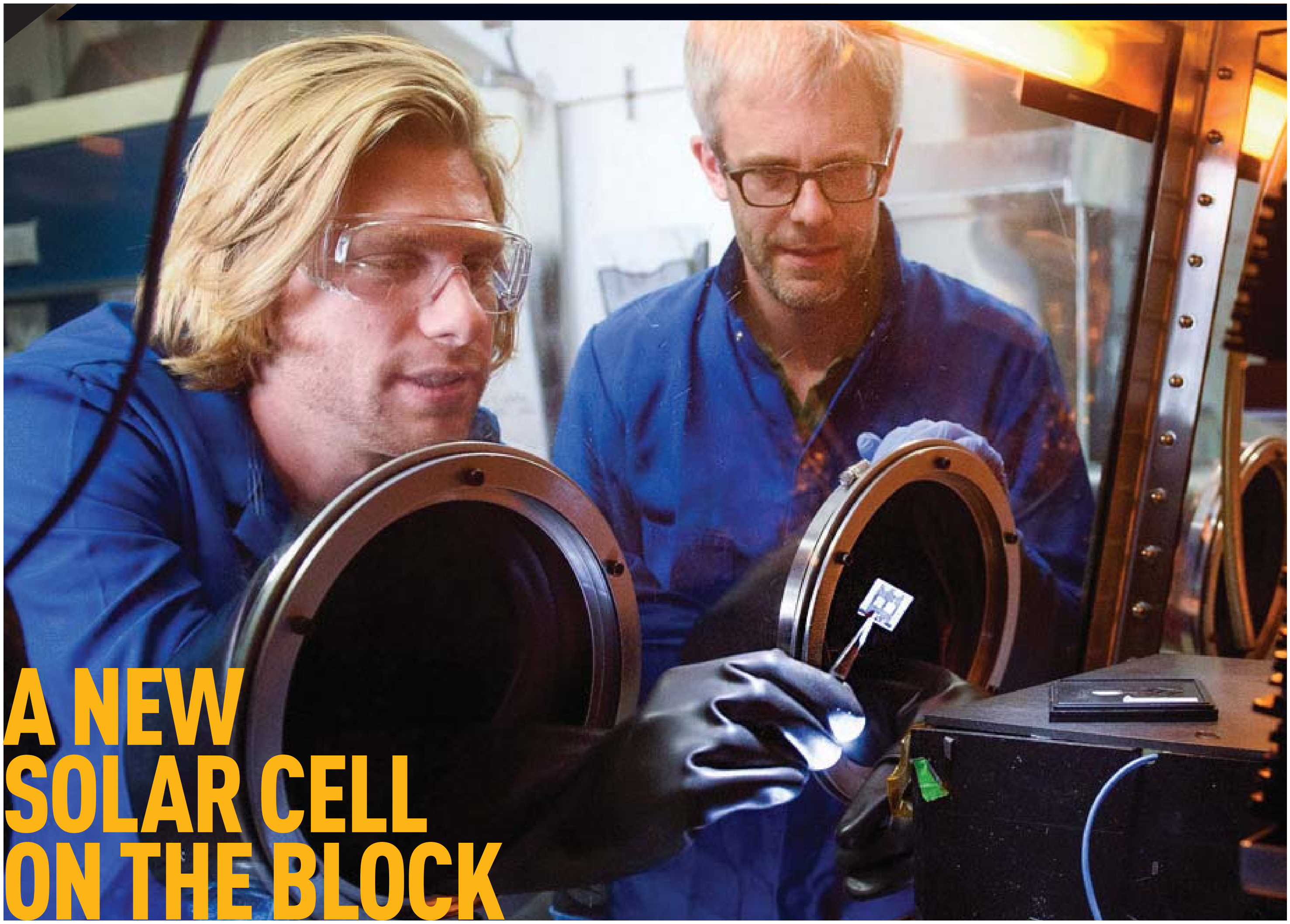

A NEW SOLAR CELL ON THE BLOCK

Tomas Leijtens (left) and Mike McGehee examine perovskite tandem solar cells, which promise to be cheaper and more efficient than conventional photovoltaic cells.
Image: L.A. Cicero

A new material being developed for photovoltaic panels stomps all over silicon when it comes to efficiency, cost, and flexibility.

Researchers at Stanford University in California are looking to develop photovoltaic cells that are cheaper, more efficient, and more versatile than standard silicon-based cells. In the lab, solar cells made with an artificial form of the mineral perovskite are outperforming silicon, have proved easier to produce, and have the potential to be manufactured on thin, flexible substrates.

The lab-grown perovskite has a crystalline structure similar to that found in the rock of the same name. But where natural perovskite is calcium titanium oxide, the stuff fabricated for solar cells contains lead, tin, and iodine. These materials turn out to be much simpler to process than silicon.

"We started off with a metal ammonium lead iodine perovskite. That's the basic archetypal material," said Giles Eperon, a postdoctoral research fellow at Stanford who has been working to make the new cell viable. "Since then we've been swapping things in and out."

By substituting tin for lead and bromine for iodine, the researchers have been able to fine-tune the absorber. "Basically, you have a really good optical material, and you can put the band gap wherever you want it within this wide range we have," Eperon said. "Conceptually it's easy. From an engineering point of view, it comes with a whole host of challenges."

> **"CONCEPTUALLY IT'S EASY. FROM AN ENGINEERING POINT OF VIEW IT COMES WITH A WHOLE HOST OF CHALLENGES."**
> **— GILES EPERON, POSTDOCTORAL RESEARCH FELLOW, STANFORD**

For instance, perovskite with tin crystalizes very quickly. That causes a problem when trying to fabricate a crystal via spin-coating deposition. That's when a solution is spun off into a substrate, leaving a thin, wet layer which is then heated until it crystallizes.

"With the tin-based material, it was crystallizing so fast it was effectively forming the final crystal materials while it was spinning," Eperon said. "That

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FLOATING BAGS MAY SCOUR PLASTIC WASTE

Around 288 million tons of plastics are produced each year, and as much as 10 percent of that finds its way to the ocean as waste.

The Dutch inventor Boyan Slat is developing a plan to clean out that waste. His plan, called Ocean Cleanup, is to float an array of barriers anchored to the seabed. The floating barriers would catch debris on the ocean's surface and force it to move along the barriers toward a platform where it would be extracted. The plastic waste that is collected could then be recycled.

The ocean current could continue to pass underneath the barriers unimpeded so that the structure would not interfere with sea life.

The floating arrays will have to with-

stand waves, storms, and brushes with large sea creatures.

Computer models tested the devices under harsh weather conditions. In simulations, the system was able to maximize plastic cleanup under normal conditions and withstand extreme storms.

Slat conceived of the idea as part of a school science project when he was 17 years old, and it is now being realized through prototype tests at Marin Wageningen, the Maritime Research Institute of the Netherlands.

Slat has assembled a global team of 100 people, many of whom are volunteers. His team has conducted a feasibility study of how Ocean Cleanup would perform in the North Atlantic Garbage Patch, a region of ocean where floating plastic waste accumulates.

A round of crowdfunding has enabled Slat to begin building a large-scale platform he hopes to deploy by 2020. ME

BEN TAYLOR, ENGINEERINGFORCHANGE.ORG

RAPID REWARMING OF CRYOPRESERVED TISSUE

In what is potentially a major advance, a University of Minnesota-based research team has demonstrated a new process to successfully rewarm large-scale animal heart valves and blood vessels preserved at very cold temperatures.

The new technique may increase the availability of human organs and tissues for transplantation through tissue and organ banks.

The researchers demonstrated they could quickly and uniformly warm preserved tissue with no tissue damge.

For decades, researchers have cooled biological samples to strikingly low temperatures without forming ice crystals, in a process known as vitrification. The samples can be preserved in such a state, but recovering them is a problem. As they're rewarmed tissues often incur major damage, making them unusable.

Working with porcine arteries and heart valves, the researchers addressed the rewarming problem by developing a new method in which silica-coated iron oxide nanoparticles are dispersed throughout a solution infusing the tissue prior to cooling.

To reheat the sample, the iron oxide nanoparticles are activated by noninvasive electromagnetic waves. The nanoparticles uniformly warm tissue at a rate of 100 to 200 degrees Celsius per minute, up to 100 times faster than previous methods. Afterwards, none of the tissues displayed signs of damage.

The research, a culmination of trials preserving or destroying cells and tissue at both ultrahigh and ultralow temperatures, was published in *Science Translational Medicine*.

John Bischof, a mechanical engineering and biomedical engineering professor at the University of Minnesota and senior author of the study, notes that in the past, researchers could thaw tissue only in small volumes of solution.

Now, for the first time, they can thaw up to 50 milliliters. This is a strong signal that the process could scale up to a larger biological system, such as organs.

"Our approach spreads the heat throughout in a way that has not been possible with other warming technologies. We believe the nanoparticles that can do this in a noninvasive RF field are biocompatible and can be washed out," Bischof said.

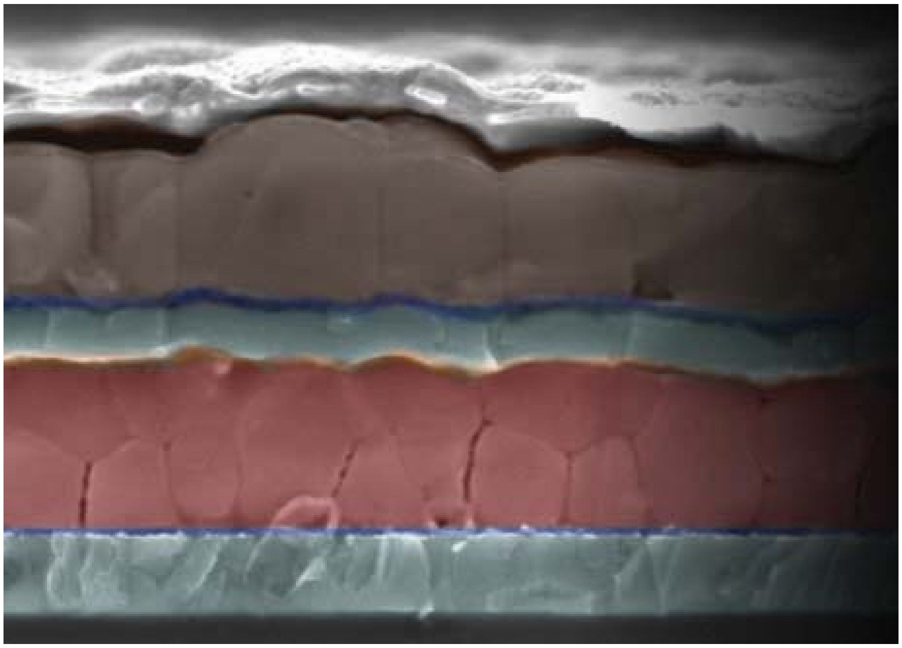
Scaling up the system to accommodate entire organs will require more advanced optimization, but the authors are optimistic. They plan to start with hearts from rodents and rabbits, then kidneys from rabbits and ovaries from pigs, and eventually human organs.

"These are very preliminary physical studies that will need to be followed by careful biological and clinical testing over a number of years," Bischof said.

The technology also holds potential beyond cryogenics, too, such as delivering lethal pulses of heat to cancer cells.

For more on this topic, see the feature, "Organ Banking," on page 44. ME

MEREDITH STETTNER



A cross-section of a tandem solar cell: the brown upper layer captures low-energy lightwaves, and the red layer captures high-energy waves.
Image: Rebecca Belisle and Giles Eperon

continued from page 12 »

CHEAPER SOLAR CELLS

has bad implications for the morphology of the film."

To slow the crystallization, and leave the film smooth rather than rough, the team dove into the literature. They found that by adding the solvent dimethyl sulfoxide, they were able to slow crystallization, after which they used an antisolvent wash to remove any remaining dimethyl sulfoxide molecules.

In the past, researchers have steered clear of tin-based perovskite, because of its sensitivity to oxidization. By mixing in lead, Eperon managed to make an alloy that was just as stable as lead.

Producing perovskite is cheaper and more eco-friendly than producing silicon. Where silicon requires temperatures of 3,000 °F, perovskite can be processed at room temperature. Nor does it require the toxic chemicals needed to treat silicon.

Perhaps the biggest advantage is the fact that perovskite is solution processable: It can be used with inkjet printing, slot-die coating, and spray coating. Silicon has to be sliced into rigid wafers and will never be sold by the roll.

PRODUCING PEROVSKITE IS CHEAPER AND MORE ECO-FRIENDLY THAN PRODUCING SILICON.

Before perovskite solar cells can be printed out like so much newspaper, however, there are still a few challenges to tackle. The cells Stanford team is making have 10 different layers, ranging between 2 and 500 nm in thickness, that must stay separated. That's not too difficult for the cells they have made in the lab, which measure less than a square centimeter.

"We need to be producing tens-of-centimeter squares if you want to make a module," Eperon said. "And with solution-processing it's an unanswered question as to how effectively you can solve that."

Already, Eperon and his colleagues have—in the lab—beaten silicon for efficiency with a conversion rate of better than 20 percent. "We've been working on pushing it further and further," he said. "Really, the remaining question is how far can it go?"

MICHAEL ABRAMS is a technology writer. For more on clean energy go to ASME.org.

WHO REALLY OWNS YOUR ENGINEERING DATA?

What would you do if the engineering models you use to manage your bills of materials, cost estimates, and manufacturing processes were held for hostage?

This is the problem now faced by the first businesses to switch to subscriptions from perpetual licenses for design, engineering, and PLM software. Subscriptions still offer many advantages, but only if companies develop a strategy to navigate what happens when their contract ends.

Until recently, most vendors sold perpetual licenses that let engineers use their software indefinitely. If engineers paid an annual maintenance fee (up to 22 percent of the initial purchase), they also received updates, bug fixes, and support.

In the last ten years, vendors have increasingly adopted subscription licensing, where regularly scheduled subscription payments replace upfront license costs and maintenance. Users can readjust the number of subscriptions at the end of each contract to match their needs. Some companies, such as Autodesk, even let users employ modules they need without locking users into specific modules with "named-user" licensing.

In theory, subscriptions work for everyone. Subscriptions give vendors predictable sources of income. Buyers pay lower upfront costs—as little as 30 percent of a perpetual license per year. It takes five to seven years for total subscription costs to exceed that of a perpetual license plus maintenance. By then, accountants would have fully depreciated the cost of a perpetual license and engineers would want to upgrade.

This win-win is why Gartner expects more than half of engineering, design and PLM software revenue will come from subscription and cloud licenses by 2020. Several emerging cloud-based vendors, such as Onshape, SimScale, and Propel-PLM, are subscription only. Autodesk and PTC deliver subscriptions only. Dassault Systèmes and Siemens offer subscription options for much of their portfolio.

WHEN YOUR SUBSCRIPTION ENDS, VENDORS CAN LEGALLY PREVENT YOU FROM ACCESSING YOUR MODELS AND DATA.

Now, some issues have emerged.

The first involves pricing. To encourage customers to switch to subscription licensing, vendors have increased perpetual software maintenance costs by 30 to 70 percent. This brings annual maintenance costs close to annual subscription costs. Some vendors also boosted prices for those converting to subscriptions, though the increases were smaller (15 to 20 percent) and discounts were possible.

The second issue involves renewal. What if your vendor raises prices? Or requires you to buy additional services? Or you want to move to another vendor?

Unfortunately, when your subscription ends, software vendors can legally prevent you from accessing your models and data. Even if your models reside on servers next to you, you cannot use them.

In the past, engineers might have continued to use legacy software while negotiating a better deal. Without that option, they have considerably less negotiating leverage. Customers must pay to access their content or pay even more to migrate data to another supplier.

How can you mitigate this challenge?

START NOW. Negotiate now. As subscriptions become the norm, vendors will be less likely to make concessions.

ADD CAPS. Insist on contracts that cap maximum increases from contract to contract and any additional services you are required to buy.

SAY GRACE. Demand vendors give at least six months' grace (with arrears paid retroactively) if you cannot reach an agreement when a contract ends.

PLAN MIGRATION EARLY. Develop a plan for large scale data migration. If possible, have vendors store data in formats that use widely accepted standards so they are easier to transfer.

DEFINE HELP. Negotiate and document vendor assistance provisions for each possible exit scenario.

Subscriptions offer many benefits, but only preparation can prevent a data hostage situation. ME

MARC HALPERN, P.E., is a vice president for research at Gartner, Inc. in Stamford, Conn.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Q&A JAY ROGERS

JOHN "JAY" ROGERS TURNED a family passion into Local Motors, a Phoenix-based company focused on the low-volume manufacturing of open-source motor vehicle designs. The company demonstrated its potential in 2007 with the Strati, the world's first 3-D-printed car. Last year, Local Motors unveiled the Olli, a self-driving 3-D-printed shuttle bus built on the company's philosophy of micromanufacturing.

ME: What is co-creation and why did you launch microfactories?

J.R: Co-creation is online design in partnership with a community. It is thought of as the fastest process to get to the best idea with the least amount of capital. The way to engage that community is to build the ability to make those co-created products come to life quickly. Low-capital factories—or microfactories—are retail points and instruments to make that happen.

ME: Local Motors now plans to produce 3-D-printed cars. What will be different about your manufacturing process and production?

J.R: The most important part is the speed of manufacturing new iterations. Instead of Henry Ford's economy of scale, this is economy of scope. That means is there is no tooling cost, so you can change the design without a problem and adopt technology quickly. You can map the physical structure to meet the electromechanical, and there is no tooling cost penalty to make the change.

ME: What is the difference between the Strati and other 3-D-printed cars such as the Urbee?

J.R: Strati is not just a 3-D-printed car. It has three processes going on. Once we have a digital design, we print it. Then we go to the second process, which is the milling process, where we router out the surfaces and interfaces. Then we go through the rapid assembly process where we attach all the parts and drive the car. So it's really printed, cut, and assembled.

Urbee was an aluminum-chassis vehicle that used a Stratasys printer to put 3-D-printed panels over it. A Chinese vehicle and one in Singapore followed the same process. Local Motors uses 3-D printing for its chassis and body together so that we can bolt components directly to it. So there is no longer a separate chassis or body–it's all one thing.

ME: What does 3-D printing mean for American manufacturing?

J.R: Free-cast additive—printing in free space driven by a numerically controlled design—will have a huge impact on automotive manufacturing as it allows us to seriously reduce tooling costs. The places where it's appropriate are where you want to save on materials, costs, or increased surface areas, places where you are heavily penalized for changing the design. Many tools in this kit bag are going to revolutionize automotive. For things like wheel and tires, I like the adage that you don't need to reinvent the wheel. You just won't use additive, as it's not justified.

ME: Your grandfather owned the Indian Motorcycle Company. What did you learn from him—and what advice can you give other entrepreneurs?

J.R: My granddad was a manufacturer and entrepreneur. He started before World War II and then purchased the Indian Motorcycle company. What I learned from him was that when you stop making, you stop innovating. When you dream of being an entrepreneur, especially in the manufacturing space, you have to get your hands dirty in order to understand the direction you want to go.

I also would want tell people in America that too much of our venture capital is slanted toward Internet technology, web apps, and biotech. We have very few people in the VC world who understand manufacturing. I encourage future entrepreneurs in the manufacturing space to think hard about how they capitalize their company. **ME**

CHITRA SETHI is managing editor at *Mechanical Engineering* magazine. This interview is adapted from an article previously published on ASME.org.

A LUNAR GREENHOUSE

What would you send to the moon? Two University of Illinois engineering students answered that question by designing a miniature greenhouse intended to enable humans to grow foodstuff from lunar soil.

The design was part of a competition sponsored by Team Indus, one of five teams in the world working to build a privately funded spacecraft capable of a soft landing on the moon.

The Bangalore-based Team Indus hopes to capture the Google Lunar Xprize by successfully landing a robot on the moon, exploring 500 meters, and sending high-definition video and still images back to Earth.

To increase the opportunity for lunar research, Team Indus created a competition of its own, challenging college students from around the world to design and build an experiment that could help develop sustainable life on the moon. Winning projects would join the lunar voyage. The competition attracted 3,000 entries.

Among them was the Regolith Revolution, developed by freshman engineering students Alex Darragh and Matt Steinlauf. The greenhouse they designed is about the size of a beverage can and is comprised of an Archimedes screw to drill into the ground, lift the lunar soil (called regolith by planetary scientists) into the shell, and drop it into rotating cups.

Once the hole closes, the device pressurizes and heats. Tubes then deposit seeds, water, and fertilizer into the cups.

The students worked with *Arabidopsis*, a type of mustard plant, and tested different fertilizer solutions to find the one that works the best with lunar soils.

"The idea and design could also be used for other planetary bodies like Mars," Steinlauf said.

Darragh and Steinlauf were selected along with two dozen other teams to present their idea at the Lab2Moon Challenge in Bangalore in March. The students had three days of presentations in Bangalore before a set of judges. Ultimately, Regolith Revolution won a spot on the lander, contingent on finding corporate sponsorship.

"Essentially, they allocated a spot for us on the lander and we just have to find a way to pay for it," Steinlauf said. **ME**

MEREDITH STETTNER

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There is currently a boom of new high-performance products and novel manufacturing processes. Driven by this boom, the demand for materials with superior properties is also growing. To keep up, a new design paradigm has emerged. It integrates the design of products, materials and associated material processing by linking engineering and material models with different scales as well as different types of physics.

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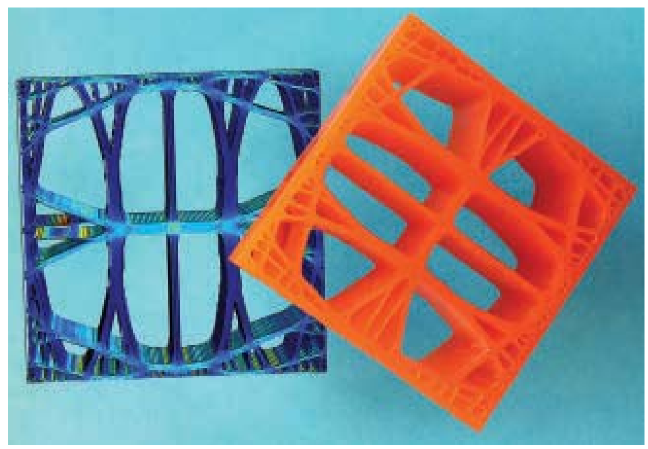
In this webinar, you will get an introduction to multiscale modeling and its material design capabilities as well as see a live demo in COMSOL Multiphysics®. There will be a Q&A session at the end of the program.



Topology optimization result in the COMSOL® software. Left: Simulation results showing mechanical stress for an optimized design with one planar direction having half the stiffness of the other. Right: 3D-printed samples.

SPEAKERS:

ERICA COENEN
Director of Engineering
Reveal Energy

MARCO BARINK
Biomechanical Engineer
Holst Center

SANDER GIELEN
Senior Consultant
PNO Consultants

VALERIO MARRA
Marketing Director
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MODERATOR:

CHITRA SETHI
Managing Editor
Mechanical Enginering Magazine

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These scales made from alumina mimic those found on the alligator gar.
Photo: McGill University

ENGINEERS HAVE LONG EMULATED THE systems and elements found in nature to solve design challenges. Advanced computational, simulation, optical, and 3-D printing tools are expanding the field of biomimetics, making it easier for engineers to transform natural wonders into practical products. This month, we look at two labs who borrow elements from animal armor to create new types of protective materials.

PREHISTORIC BODY ARMOR
THE LAB Department of Mechanical Engineering at McGill University, Montreal; Francois Barthelat, associate professor.
OBJECTIVE Developing strong, flexible body armor.
DEVELOPMENT Drawing inspiration from a primitive fish to create armor that is more puncture resistant than commercially available materials.

When two engineers at McGill University in Montreal set out to create a new type of body armor, they turned to the aquarium for inspiration.

Postdoctoral researcher Roberto Martini and associate professor Francois Barthelat were looking for something both puncture resistant and flexible. At first, they explored the physiology of striped bass. But the bass, a recently evolved fish, paleontologically speaking, has scales designed to protect against small predators.

The alligator gar, however, has changed little since the Early Cretaceous period 100 million years ago, when the ancient species developed much stronger scales to fend off plesiosaurs, mosasaurs, and other large swimming reptiles.

"You can't cut it with a hacksaw," said Bathelat, who relied on atomic-force microscopy to examine the structure of the scales and how they interact with their neighbors.

Other research teams have developed fish-scale armor using polymers, but while those materials provide good protection against lacerations, they do not prevent punctures, Barthelat said. Barthelat and Martini opted instead for high-purity alumina, which is relatively inexpensive, widely available, and highly puncture resistant. They cut the alumina into strips that measured 5 mm wide, 115 mm long, and .6 mm thick, and then scored the surface at roughly 11.5 mm intervals.

The researchers bonded the alumina strips to prestretched pieces of polyurethane and broke up the strips at the score marks to create ten separate scales. When the team relaxed the tension on the polyurethane, the new scales overlapped each other to form a tough yet flexible surface. The team later swapped out the polyurethane for a flexible, cushiony membrane that can be attached to fabric.

In their tests, which were reported in the journal *Bioinspiration and Biomimetics*, the researchers mounted a steel nail with a .37 mm tip to a testing system and repeatedly drove it into the scales at 100 N, or 22.5 pounds of force. The scales repelled the nail. The scales were vulnerable, however, when the nail slipped under or between scales. The researchers say a thin coating applied over the scales should help keep the unprotected areas under the scales from being exposed.

The team is working with a manufacturer to use the material for protective gloves and is creating applications for other gear, such sporting and military equipment. "In the long term, nature has a lot to teach us because it has played this game millions and millions of times," Barthelat said. **ME**

Engineers have long been fascinated with the properties of the beetle exoskeleton. In theory, the material is both light and strong enough to serve as the body of automobiles, but researchers haven't replicated the material in the lab, mostly because they have never been able to develop a nanoscale method to characterize or identify the twisting fibers of chitin that make up the exoskeleton.

Now, a team from Northwestern University's McCormick School of Engineering has used an atomic force microscope to identify the twist angle between the layers of fibers, the diameter of the fibers, and the pitch size of the twisting, or helicoidal, patterns found in the exoskeleton of the figeater beetle, a field crop pest native to the western United States.

"We investigated the helicoidal shape to understand the design rules for developing composites," said Horacio Espinosa, an ASME Fellow who is a professor of manufacturing and entrepreneurship at Northwestern.

Structures composed of fiber layers that twist around like a helix or screw are one of the most common forms in natural materials. To better study those helicoidal structures, Espinosa's team sliced through the material to get a cross-section that exposed closely packed fibers pointing in different directions. The AFM tip was able to not only image the fibers, but measure some of their material properties as well.

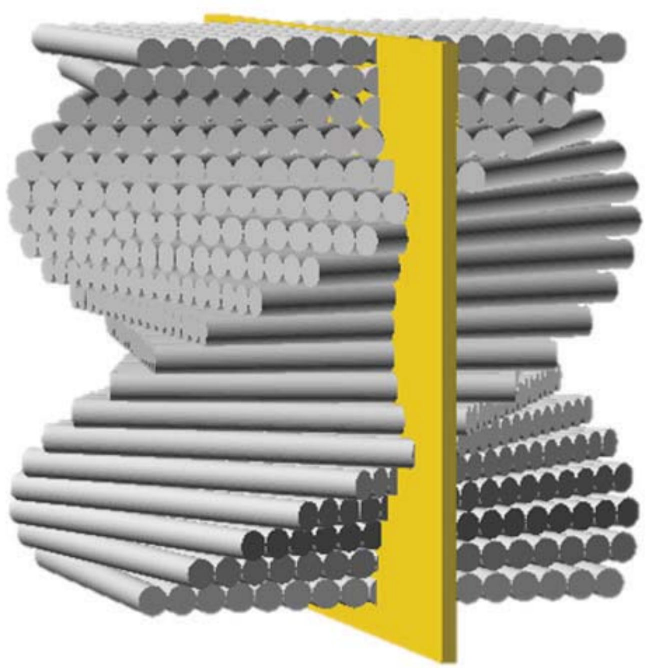
The twist angle between the layers of fibers ranged from 12° to 18°, and the pitch size was 200 nm for a complete turn. The shear modulus for the material was found to be 90 MPa.

The data was published in a recent issue of *Advanced Functional Materials*.

The discovery of the properties should make it easier to use advanced 3-D printing methods to create new materials, such as light, highly impact-resistant skins for cars, aircraft, and other types of vehicles and products. The lab is now creating some of those new materials, Espinosa said.

"People say, 'I can make this much bigger and get the same results,' but it's not that simple," he said. "You have to look at all the variables that control the properties of the material, and then you can address how to make it without a lot of imperfections." **ME**

JEFF O'HEIR is a technology writer in Huntington, N.Y.



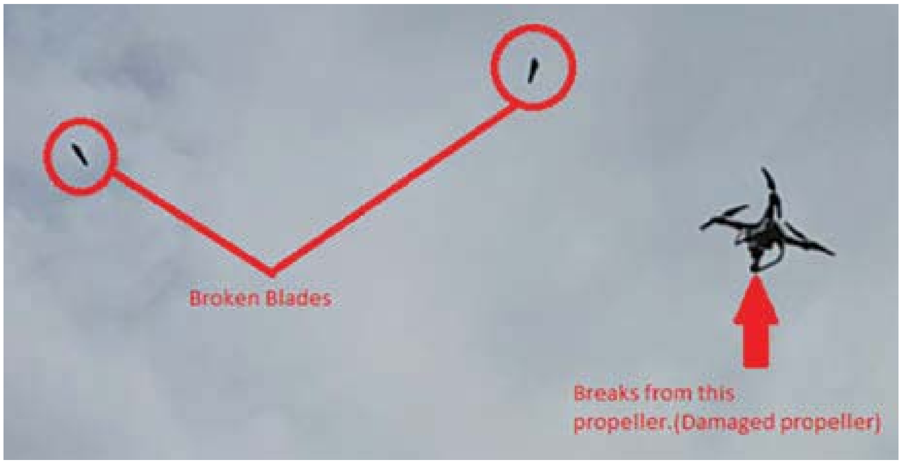
The exoskeleton of a figeater beetle are made of chitin fibers in closely packed helices. *Image: Northwestern University*

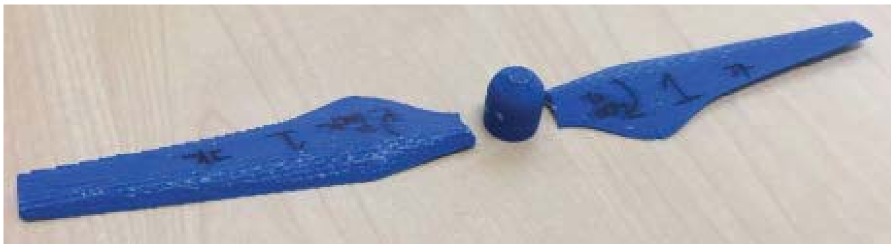
MEASURING A TWIST

THE LAB Micro and Nanomechanics Laboratory, Northwestern University in Evanston, Ill.; Horacio Espinosa, group leader.

OBJECTIVE Understanding the behavior of materials across scales and developing engineered devices for both materials research and biological applications.

DEVELOPMENT Creating a method to identify the geometry and material properties of structures within the fibers that comprise the exoskeleton of the figeater beetle.





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3-D PRINTER: DRONE HACK

called a "reverse tunnel" into the computer hosting the design. They manipulated the design and inserted cavities into the propeller blades. The cavities caused the propeller to break in mid-air.

In theory, the quality-control process could catch defective parts made from sabotaged design. But in this case, the additively manufactured drone wing was sabotaged in a way that would escape detection during typical quality-control measures.

"All of these tests have limits [in terms of] defects that can be detected," Yampolskiy said.

A physical inspection could also

Defects inserted in the control files for a 3-D printer weakened blades on this quadcopter, causing a crash.
Image: Mark Yampolskiy, Univ. of South Alabama

have revealed the problem, said Sven Schrecker, chief architect for IoT security solutions at Intel. However, "the novelty in this particular attack is that the compromise is digital, the tampering is very subtle and may not have been caught, as it is not visible to the human eye," he said.

The part was also sabotaged to not fail right away—another way for the product to make it through manufacturing quality control, then fail when in use.

To prevent sabotage attempts, one possible solution would be to create designs of functional parts with a higher safety factor, Yampolskiy said. But this would increase size, weight and cost, which would make this approach impractical and unlikely, he said.

Another approach would be to develop the ability to detect ongoing or already successful attacks, but this would require better quality control measures than are currently available.

The demonstration is already forcing the additive manufacturing industry to adopt cybersecurity best practices by making sure software and firmware are up to date; constantly monitoring network traffic; and creating an air gap between the internet and the production network, he said.

The integrity of each product and component in the supply chain must also be attested to, Schrecker said. "The owner or operator of the equipment must be able to interrogate each component of the system to attest to that element's integrity. Each component, in turn, interrogates its subcomponents to attest to their integrity and, when complete, reports its findings."

After successfully showing that 3-D-printed designs can be hacked and sabotaged, Elovici and Yampolskiy have turned to preventing attacks before they succeed. A thwarted sabotage may not make for an exciting YouTube video, but it would be an important step forward. **ME**

KAREN HAYWOOD QUEEN is a technology writer based in Williamsburg, Va.

"IF YOU'VE GOT MORE LAX SAFETY standards worldwide, I think that's a problem from an industry perspective as well as just a human standard."

— Richard Nephew, a senior research scholar at the Center on Global Energy Policy at Columbia University, on the potential damage to nuclear safety and waste management standards if the United States abandons nuclear power, as quoted in the New York Times on Feb. 18, 2017.

CHINESE MANUFACTURERS PLAN TO DOMINATE ADVANCED TECHNOLOGY

China assembles 80 percent of the world's computers and 90 percent of its mobile phones. Yet it remains an also-ran in the advanced engineering, IT, and manufacturing processes that make these and other emerging technologies possible.

The Chinese government plans to invest $300 billion to change this, and to wean the country off imports from companies like Boeing, Airbus, General Electric, Siemens, Nissan, Renault, Samsung, and Intel.

Under its new "Made in China 2025" initiative, China will invest in 10 high-tech industries. These range from automation and robotics, energy, new materials, and IT to aerospace, electric vehicles, ships, rail, biopharmaceuticals, and electrical and agricultural equipment.

The government plans to support these investments through a combination of subsidies, support for state-owned enterprises, limits on market access for foreign business, and state-backed acquisitions of Western companies, the European Chamber of Commerce in China wrote in a recent report.

Its investments could be game-changers. China plans to invest €2.7 billion in advanced manufacturing, about 13 times more than Germany invested in its Industrie 4.0 initiative.

UNDER ITS NEW "MADE IN CHINA 2025" INITIATIVE, CHINA WILL INVEST IN 10 HIGH-TECH INDUSTRIES.

According to the Chamber, China's "semi-official" goals for 2025 include domestic market shares of 80 percent for electric vehicles, high-tech ship components, and energy equipment. It plans to achieve 70 percent for robots and advanced medical devices, and 60 percent for large tractors and harvesters.

China's leadership has long recognized that China does not drive technology advances. The country faces two key issues. First, lax intellectual property enforcement has discouraged Chinese companies from investing in research and development, since competitors can copy with impunity.

This seems likely to change, said Alberto Moel, a senior research analyst at the financial services firm Sanford Bernstein Hong Kong. Permissive IP policies helped manufacturers learn from foreign companies, but China will enforce IP rules to protect domestic companies. "Chinese industrial policy is very well thought out and directed," he said.

China must also cope with changing manufacturing technology. Low-cost labor drove its initial success. While some companies, such as Taiwan's Foxconn, which assembles Apple, Amazon, and Microsoft products in China, are highly automated, most Chinese producers are not. China has only 49 robots per 10,000 workers, compared with more than 300 in Germany and Japan and 500 in South Korea. This leaves China at risk of falling behind the productivity and quality of global competitors.

On the other hand, China has hundreds of millions of middle-class consumers. Many advanced technology manufacturers built factories in China to sell to those consumers and the industries that support them.

Chinese policies that give Chinese-owned manufacturers an advantage would hurt those companies. And because Chinese markets are so large, Chinese firms could potentially achieve the economies of scale needed to drive costs down low enough to swamp global competitors.

This could lead to a protectionist backlash.

Still, 2025 is a long way out, cautions Tim Bajarin, president of Creative Strategies and a leading tech consultant.

"What is unclear is how the Chinese will enforce this, and what the actual regulations are going to be," Bajarin said. If China seeks to impose tariffs or restrict U.S. firms, President Trump might respond with new U.S. barriers on Chinese goods. Right now, he calls the situation cloudy with a lot of talk.

"Until we know what the rules are, it's hard to tell," he said. ME

MEREDITH STETTNER

INTEL INVESTS $15 BILLION IN SELF-DRIVING CARS

Intel plans to buy Israel's Mobileye for $15.3 billion, in a deal that Intel said will let it deliver end-to-end solutions that stretch from its own silicon, wireless, and Big Data technologies to Mobileye's computer vision and mapping solutions.

Ultimately, Intel will offer complete systems that automakers could incorporate into new vehicle designs. It hopes that engineers would find this easier and cheaper than integrating components and IT from different vendors.

Intel used the same systems approach to grow its PC and data center businesses, and thinks it will work in autonomous vehicles as well. "I don't believe that every car manufacturer is going to be able to invest the money to do independent development of this," Intel CEO Brian Krzanich said of autonomous driving systems.

The purchase represents a bid by Intel to become a dominant player in the autonomous car market. Intel is paying more than 40 times Mobileye's total annual revenue. To justify the price tag, which is nearly one-tenth of its total stock market capitalization, Intel must find ways to use Mobileye's vision platform to dominate the market through rapid introduction of new technology at scale, the way it did with PC processors in the 1980s and 1990s.

Mobileye uses cameras and software algorithms to monitor the road. More than 16 million cars—about 80 percent of the driver assistance market—use its EyeQ systems to warn when a car leaves the lane or to spot impending accidents and tell the car to brake autonomously.

Mobileye is also developing a cloud-based technology that synthesizes data from cars with the company's cameras to create a high-definition map of where they've driven, and provide that to other cars on the road.

Many people believe that fully autonomous vehicles will need such high-definition maps to operate without human intervention. The need for such maps is pressing: Intel, Mobileye, and BMW have announced plans to field autonomous test cars by the end of this year.

In the past, Intel lost out to U.K.-based chip maker ARM on the market for smartphone chips. Its purchase of Mobileye ensures that it will remain in the game as autonomous vehicles take to the highways. ME

WHAT EVER HAPPENED TO THE WANKEL ENGINE?

LOOKING BACK

Innovative engine technologies were of great interest when this article was first published in May 1977.

FRITZ HIRSCHFELD, HISTORIAN, WASHINGTON, D.C.

Curtiss-Wright invested close to $40 million and nearly two decades to make Felix Wankel's rotary engine a mainstream success. Here is a look back at the technology that tried—and failed—to replace the piston engine.

NSU had granted an exclusive North American license to Curtiss-Wright against a down payment of $2.2 million in cash (plus, of course, royalties) and a commitment to substantial R&D of what was still an undeveloped principle. It seems that the ink was hardly dry on the agreement when Roy Hurley, the chief executive officer of C-W, flatly predicted that the Curtiss-Wright-NSU-Wankel engine would soon be the standard power plant for the entire automobile industry! ...

Engines were built for a wide variety of applications ranging from lawn mowers to large aircraft, but it was a case of going in too many directions at once before a basic engine building block, with both durability and performance, had been developed. It was the old story that there were too many design and production "bugs" that had not been foreseen and that kept sending the engineers back to their drawing boards. These efforts were not by and large meaningful to Curtiss-Wright because the company still had its eyes firmly fixed on its original and largest goal—the automotive business. It was a great day for C-W, and the next major milestone in the Wankel development, when General Motors signed on with C-W for a manufacturing license. With GM in the picture, it looked like a bright future for the rotary engine. Unfortunately, a storm cloud was building that would cause another setback in the Wankel odyssey.

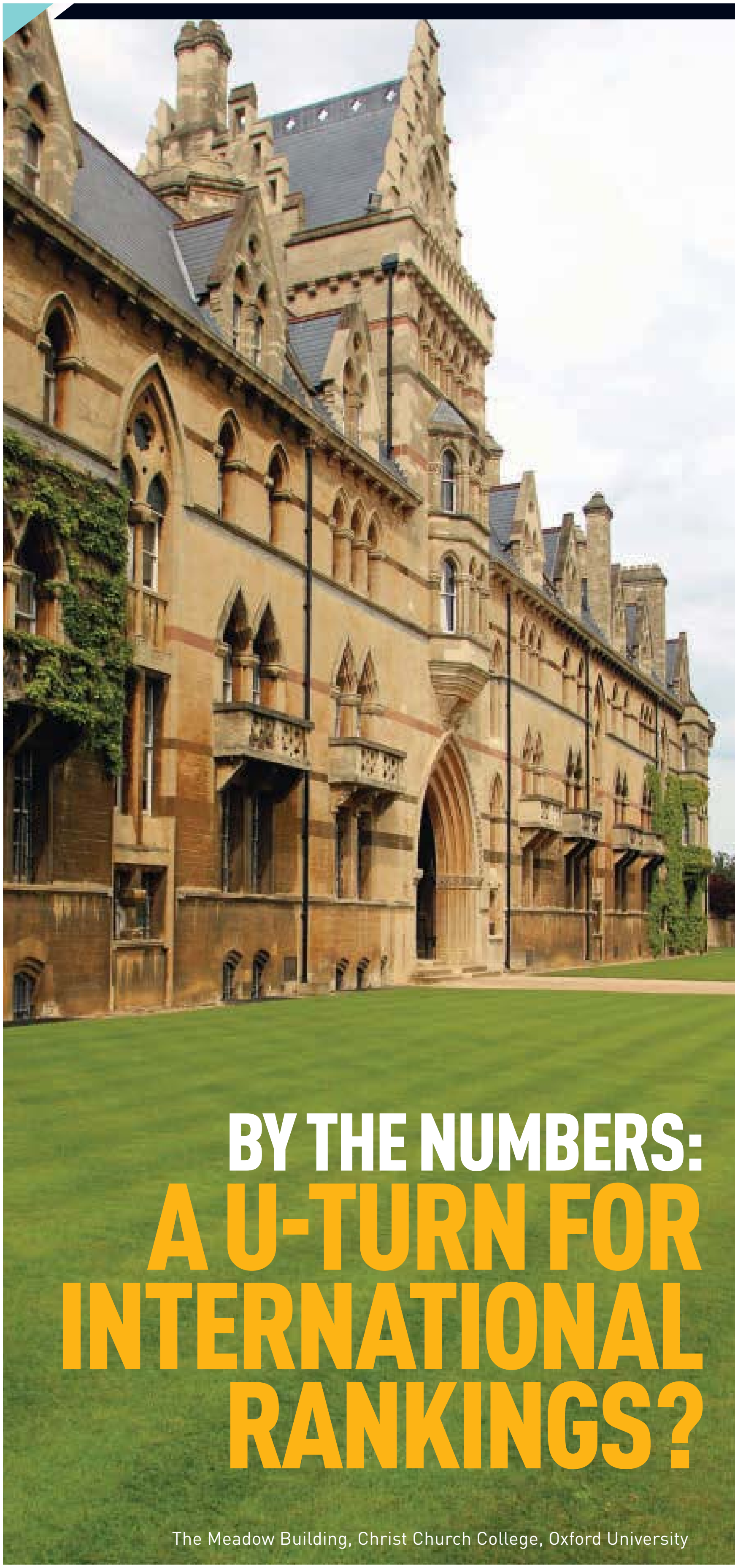
The bad news came in the form of air pollution legislation. Even the power and muscle of GM had to bend before the clean air regulations enacted by the Environmental Protection Agency. And since the Wankel had a "dirty" untreated exhaust and could not meet EPA standards its commercial prospects were again sidetracked. ...

There is a car presently on the American market powered by a Wankel rotary engine which is highly regarded by the public and which has been able to meet the EPA parameters with competitive fuel economy and superior performance. The car is the Japanese Mazda. Toyo Kogo—the Japanese manufacturer—has a direct licensing arrangement with Wankel-NSU that is independent of the Curtiss-Wright agreement. While Toyo Kogo has been able to make some reductions in the raw hydrocarbon emissions of its carbureted rotary engine, they must still incorporate an afterburner in the Mazda, which efficiently burns away almost all of the hydrocarbons so that the exhaust is practically free of these pollutants. The trouble is that the afterburner system is expensive and the added price has therefore helped to make the Mazda less price competitive. The afterburner solution, although extremely effective, does not seem to appeal to American (or European) car makers, so the search goes on to develop an intrinsically clean rotary combustion engine. **ME**

MAKING THE JUMP INTO HYPERSPACE

While Hirschfeld was charting the ups and downs of the Wankel engine, an irresistible cultural force was taking off. *Star Wars* was released on May 25, 1977, to fewer than three dozen theaters and studio executives were concerned that the expensive space adventure would be a flop. That first weekend, however, the film took in more than $1.5 million; within six months, *Star Wars* was the highest grossing movie ever. The movie's characters, from robot sidekicks C-3PO and R2-D2 to the villainous Darth Vader, quickly became cultural icons, and *Star Wars* has inspired generations of youngsters to pursue science and engineering careers. Yet another episode of the story will be released this December.

Darth Vader is now an iconic villain.



BY THE NUMBERS: A U-TURN FOR INTERNATIONAL RANKINGS?

The Meadow Building, Christ Church College, Oxford University

Most of the world's top engineering programs are in the United States and Great Britain. As those nations become less welcoming to foreigners, could their colleges lose ground?

Elections in the United Kingdom and the United States in 2016 set the stage for a reexamination of those countries' relationship with resident foreigners. The referendum over the U.K.'s status in the European Union was seen by many as a contest over immigration. Many in the majority of voters who chose for Britain to exit the E.U. did so to send the population of resident aliens packing. And in the United States, one of the first acts of the Trump administration was to restrict entry of citizens from certain countries, which had a chilling effect on all international travel to the U.S.

Another thing that the United States and Great Britain have in common is their world-class research universities. Most rankings of international universities find that the top schools are in those two countries. For instance, the *Times Higher Education World University Rankings 2016-2017* listed only one non-U.S./U.K. school—the Swiss Federal Institute of Technology in Zurich—in its top 20.

The rankings for the top engineering and technology schools is somewhat broader, with universities from Singapore, Switzerland, China, Hong Kong, and the Netherlands in the top 25, though they are still dominated by the likes of Stanford, Oxford, and the Massachusetts Institute of Technology.

But that list also shows a potential vulnerability: all the top-ranking universities have a large percentage of foreign students. In the U.S., the range runs from about 16 percent for large public universities to 34 percent for MIT; in Britain, some of the top colleges have a majority of foreign students. If those two counties start to feel hostile to foreigners, how might that affect top universities?

To play on the preoccupation that fueled Brexit, what happens when the Portuguese professors and Spanish students are kicked out, in addition to the Polish plumbers?

The *THE* methodology uses five separate metrics, one of which is international outlook, to calculate the rankings. What would happen to the relative ranks of engineering and technology schools if—to take an extreme case—one set the international outlook of British and American universities to zero, while leaving everything else the same?

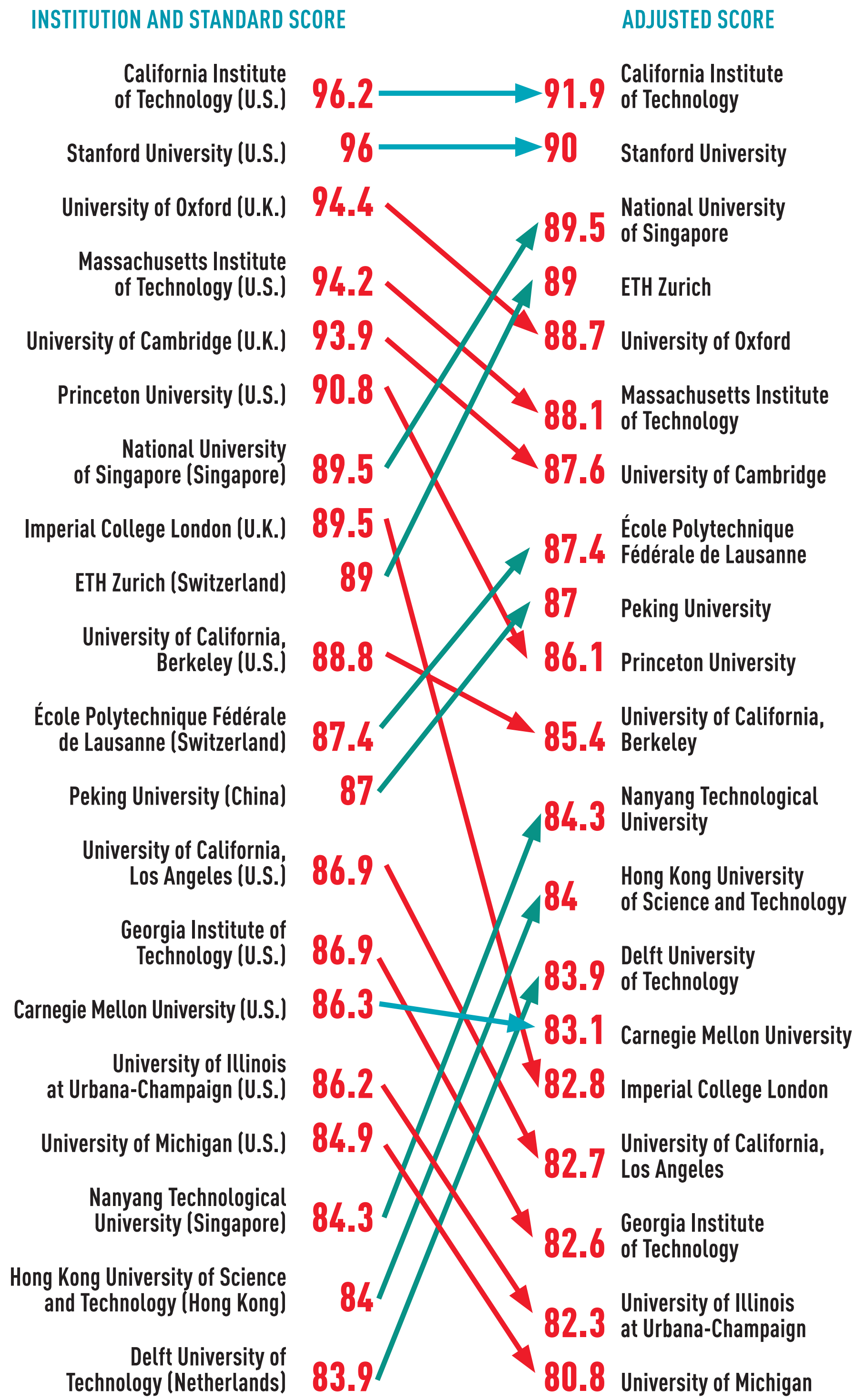
Surprisingly, not much. The relative rankings churn a bit, but the top schools are as American and British as ever. Some of that is due to the small weight that *THE* gives international outlook—just 7.5 percent of the total. But more important is the inherent strength of the schools in terms of both research and teaching. The international nature of the faculty and student body adds to those schools, but the foundation is homegrown.

To be sure, the *Times Higher Education* methodology may not capture the full impact of international students. For example, the tuition that international students pay American public universities is important, especially as state education funding shrinks. That may eventually weigh down the ranking of state universities. For now, at least, their standing should remain, even if international students start to look elsewhere for their studies. ME

JEFFREY WINTERS

University Rankings: International Impact

American and British universities dominate the top of the *Times Higher Education* rankings of world engineering schools. All those schools have extensive international ties, but even if you remove the international outlook from U.S. and U.K. universities, they still rate highly.



STRINGS ATTACHED

When U.S. startups accept funding from overseas investors, who really benefits?

BY TIM SPRINKLE

Four years ago, researchers at Massachusetts Institute of Technology released a major study, *Production in the Innovation Economy,* which analyzed how the United States might recapture its manufacturing mojo. Buried in the report was a disturbing assessment of a group of 150 manufacturing startups founded between 1997 and 2008. These firms were based on advanced MIT technology and were, arguably, among the most likely to succeed.

The authors, led by Elisabeth Reynolds, executive director of MIT's Industrial Performance Center, analyzed funding, customers, supply chains, buyers, and more. The goal was to understand how those 150 companies flourished or failed in international markets—and why they were increasingly looking overseas for support when building their businesses.

Their answer, in a word: scale.

The U.S. provides fertile ground for startups, the authors wrote. It has the rich infrastructure of specialized skills and equipment needed to build and reengineer prototypes rapidly, develop pilot production facilities, and even reach low-volume commercial production. Yet when these firms were ready to take a giant step up to large-scale processes, the search for additional capital as well as scalable production capabilities drove many firms to relocate their production abroad.

This migration, the authors argued, did more than move equipment and jobs overseas. It took with it the hard-gained tacit knowledge needed to make that equipment operate at peak performance. It led to the migration of key skills, technical capabilities, and the ability to fully understand and improve the manufacturing process outside of the country.

It also ate into the returns the public expected from investments in innovative companies through research grants and tax abatements. Even more importantly, the move overseas was dragging down the country's future capacity to innovate by gifting other nations with tacit product and process knowledge that had taken years to attain.

Four years later, we are having the same conversation all over again, albeit this time, with political undertones. As the United States and other parts of the world appear to be pivoting to more protectionist policies and attitudes, the idea of "Us vs. Them" is very much in the public eye today.

It is happening at a time when the lives and fortunes of entrepreneurs in a wide range of different industries are more global than ever. Today, founders are accepting funding from overseas investors, setting up supply chains in different parts of the world, servicing customers internationally, and even selling their businesses to foreign government-backed funds. It is truly a global economy.

As more and more U.S. manufacturing startups are becoming involved in the international economy, we have to ask how all of this is changing the landscape for U.S. entrepreneurs. Is overseas funding altering the way companies in this country do business? Are international asset sales shipping the fruits of our labor and investment overseas to help U.S. competitors?

And are domestic investors and innovators losing out?

A Changing World

There is some reason for concern here.

According to a report released in March by the European Union Chamber of Commerce in China, an organization that represents European overseas business interests, China will invest $300 billion to become self-sufficient in 10 advanced industries—from aerospace and next-generation wireless to semiconductors and electric cars—by 2025. It plans to accomplish this by creating a host of new government-subsidized competitors, enacting policies to favor their products, and investing in technology firms overseas.

If China can pull it off, this new production would effectively close off the world's fastest-growing market from overseas competitors like Apple, Ford, General Electric, Tesla, and others. According to the report, China Manufacturing 2025 aims to secure as much as 80 percent of the domestic market in each of the target industries over the next eight years. The remaining 20 percent would be all that is left for the rest of the world.

This is just one example of an ongoing trend. According to the online startup investing firm FundersClub, U.S. venture capital investment quadrupled to $83.2 billion in 2015 from $20.1 billion in 2005. In this same period, funding from overseas venture capitalists soared nearly 44 times, to $57 billion from $1.3 billion. According to the National Venture Capital Association, growing overseas funding diluted the U.S. share of global VC investment from 81 percent in 2006 to just 54 percent in 2016.

> "I travel to about two dozen countries a year, and I see a lot of investment going into science education."
>
> —Vitaly Golomb, venture capitalist and startup business advisor.

"I travel to about two dozen countries a year, and I see a lot of investment going into science education," said Vitaly Golomb, a California-based venture capitalist and startup business advisor. "And not just software development, but physics, mechanical, chemistry, etc. China is quite strong in this."

As of 2017, the U.S. still has the largest number of top 20 science universities, but that lead is shrinking quickly because of the work being done in Asia, Europe, the Middle East and elsewhere. This has helped spawn rapid growth of startup activity worldwide.

The numbers are staggering. According to the Chinese government, an average of 12,000 new companies, including both tech companies and others, were registered every day in China in 2015. That totals more than four million new companies in one year.

"Areas like Shenzhen came out of nowhere and in the last 20, 30 years have become major areas for manufacturing," Golomb said. "A lot of the world's mechanical work is happening there now, much more than is happening in the Bay Area [surrounding Silicon Valley]."

The trouble, he explains, is that the United States, and Silicon Valley in particular, effectively gave up its role as a manufacturing center decades ago, opening the door to new competition from China and elsewhere. Over the last 20 years, as the Bay Area became hyper-focused on software innovation, it lost its base of mechanical engineering and production talent.

This did not look like a big problem when apps were the primary growth engine fueling U.S. technology, but now that we are transitioning to more complex, more advanced platforms—including virtual reality, artificial intelligence, and autonomous transportation—the shortfall has become noticeable. Meanwhile, as innovation has shifted away from what Silicon Valley does best, the rest of the world has not been sitting idly by, but is stepping in to address these opportunities.

"Access to an emerging market that is approaching the size of the U.S. market is also part of the siren song."
— Scott Thielman, CTO at Product Creation Studio

For the first time in its history, Silicon Valley and the U.S. tech industry are being forced to play catch-up to more developed international competitors.

Business as Usual

Startup founders themselves do not see it that way however. For many, success in business is a zero-sum game: they either win or lose. When building up a new company, particularly in manufacturing, where barriers to market entry are steep and startup costs prolonged, there is little room for hand wringing over funding sources, U.S. economic growth, or international relations. Founders need what they need, and if they find a better deal outside U.S. borders, then so be it.

What's more, accepting international investment often means access to markets that otherwise might be difficult for a small startup to crack, explains Scott Thielman, CTO with Product Creation Studio, an engineering and design consulting firm in Seattle that helps large brands partner with local startups.

"Today, the appeal of Chinese investment goes beyond just the cash," Thielman said. "Access to an emerging market that is approaching the size of

the U.S. market is also part of the siren song.

"But many market segments are strategic to China, and the investment may be tied with building capabilities in-country," he continued. "I have seen this in the medical device space where small companies can access Chinese capital if they are willing to locate the R&D at a tech center in China." For the most part, entrepreneurs report that these arrangements, particularly when accepting investment capital from overseas sources, have little to no impact on day-to-day operations or their long-term strategy. On the contrary, access to Asian supply chains, scale-up and manufacturing talent, and other resources that simply are not available in the U.S. today, is often highly appealing to entrepreneurs as they enter the global market.

And these relationships work both ways. When overseas parties look at buying or investing in U.S. companies, it is often because they want or need access to Western design, technology, and talent. They want to partner with the startups that are driving consumer and tech trends, said Michel Marasco, director of the Farley Center for Entrepreneurship and Innovation at Northwestern University, who advises startups on overseas takeovers and investment deals.

International investors "are very much interested in understanding more about what the companies are doing," he said. "They seem to be fairly interested in using these companies as a way of establishing operations in the United States, when they don't already have some form of operations here."

"You can't define hard borders when materials, people and manufacturing processes are required from around the world."

— Scott Thielman

The cost of this activity to the U.S. GDP, if any, can be difficult to determine. Although the idea of losing American inventions and technologies to international investors and buyers is not generally good for public relations, the current landscape of global startup development has winners on both sides, and overseas involvement in U.S. companies does not necessarily mean a net loss domestically.

"That's the thing with a global economy," Thielman said. "You can't define hard borders when materials, people, and manufacturing processes are required from around the world. We should be patriotic about growing companies and technologies from the U.S., but that doesn't mean we can't leverage foreign investment to accelerate that and let them share in the winnings."

Industry Involvement

For the past 20 years, American policy has failed to help manufacturers cope with overseas competitors whose governments provided financial incentives for exports. At the same time, many established firms have moved their own production overseas, chasing low wages and lax regulations rather than investing in productivity-boosting technologies at home.

The job losses and economic issues associated with this trend are well known, but the impact on R&D is less

discussed. In a 2010 essay published in *Bloomberg Businessweek,* long-time Intel CEO Andy Grove argued that the knowledge gained commercializing volume production was critical to improving new products.

"Without scaling, we don't just lose jobs—we lose our hold on new technologies," Grove wrote. "Losing the ability to scale will ultimately damage our capacity to innovate."

Tom Kuczmarski, a Chicago-based product development consultant who works with both startups and Fortune 500 companies, would agree. In an environment where national policy—and many corporations—undervalue manufacturing at home, why, he asks, wouldn't entrepreneurs look overseas for funding and support?

Yet Kuczmarski is not a pessimist. He sees the U.S. manufacturing sector embracing innovations in production, management, distribution, and more.

"I think as we've gotten a little smarter, it's now about specialized manufacturing," he said. "It's more about creating an environment that is really aimed at entrepreneurs. Ultimately what it comes down to is that the growth of the economy comes from small companies and businesses—it doesn't come from Fortune 500 companies. So, are they able to ultimately make pieces and parts and the like within the U.S.? The answer is that it's still hard to do that, and I think that's ultimately where the challenge still lies."

The good news, Kuczmarski explains, is that more and more large corporations are figuring this out and are taking steps to actively engage with small, entrepreneurial companies and the innovators in their industries. Those who do this well will be the most successful in the global economy, whereas those who don't are going to struggle to adapt to a world where innovation is the currency of growth.

We live in a global marketplace. Each manufacturer—from a startup to a multinational corporation—must come to terms with that fact, if it wants to grow. The U.S. government must find a way to move the U.S. economy forward, preventing predatory pricing and mercantilist practices by exporters while at the same time reaping the international flow of ideas and funds that power innovation.

Ignoring the rest of the world would not only limit the growth potential of U.S. startups, but over time would reduce America's global leadership in innovation. If that were to happen, everyone loses, at home and abroad.

Ignoring the rest of the world would not only limit the growth potential of U.S. startups, but over time would reduce America's global leadership in innovation.

"Anybody that's had Economics 101 understands that protectionism doesn't work," Golomb said. "And as much as it sucks that there has been a lull in manufacturing in the U.S., there's no going back. It's a global market, and there's no reason for U.S. companies to sit there ignoring the rest of the world." **ME**

TIM SPRINKLE is a technology writer in Denver, Colo. His work has appeared in *Wired, The Atlantic, Outside,* and elsewhere.

THE STATE OF AMERICAN MANUFACTURING 2017

BY ALAN S. BROWN

Five snapshots reveal the challenges the nation must meet before it can revive its manufacturing sector.

What made manufacturing one of the central issues of the last presidential election? Some experts point to a chart (reproduced below) that plotted output per worker, or productivity, against factory employment. While productivity made steady gains over several decades, employment declined—then collapsed.

Indeed, more than 70,000 U.S. factories closed and 5 million manufacturing jobs evaporated between 2000 and 2016.

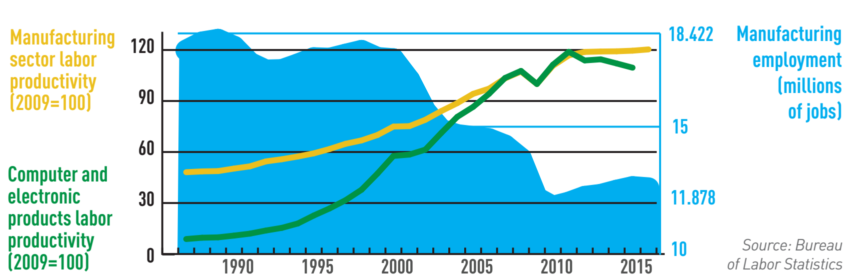
However, that seemingly simple chart can be interpreted in different ways.

According to one reading, as automation and information technology made factories more efficient, they needed fewer workers. In 1980, manufacturers needed 25 workers to produce $1 million worth of products, according to Mark Muro, a senior fellow at the Brookings Institution. Today, thanks to automation, they only need 6.5 workers.

But that might not be the whole story. The Information Technology and Innovation Foundation, a highly respected policy think tank, notes that productivity has been growing at a steady rate for decades. Why did the job losses accelerate only after 2000?

The ITIF believes manufacturing productivity gains in recent years may be overstated. Much of it has been driven by the computers and electronics sector, which defines output in terms of processing capacity, not the number of computers and chips produced. (That actually fell from 2000 to 2010.) Calculate

FACTORY PRODUCTIVITY RISES WHILE EMPLOYMENT FALLS



manufacturing productivity without computers and electronics, and it rose more slowly from 2000-2010 than it did the previous decade.

Instead of rising productivity, ITIF blames job losses on Chinese imports, which rose dramatically after China joined the World Trade Organization in 2001.

Instead of trying to explain the entire state of American manufacturing in a single chart, we offer five snapshots, each unfolding from a slice of relevant data. Together, they present a picture of a dynamic component of the economy: one that is larger and more complex than politicians or the popular press realize.

BLURRING THE LINES

Manufacturing is still often defined by a physical transformation: milling, molding, assembly, and so on. But two recent trends—outsourcing and digital services—have enabled manufacturers to stretch that old definition to the breaking point and made it difficult for statistics to capture the entirety of the manufacturing sector.

Most engineers are familiar with outsourcing production work to other factories. While many consumer products companies outsource manufacturing overseas, they often design, engineer, test, source, and manage the logistics of their supply chain in the United States. Those are tasks identical to ones performed by manufacturing employees, yet none of their employees are counted as working for manufacturers. According to a U.S. Census Bureau estimate, at least 54,000 factoryless firms employing 3.4 million workers purchased contract manufacturing services in 2012.

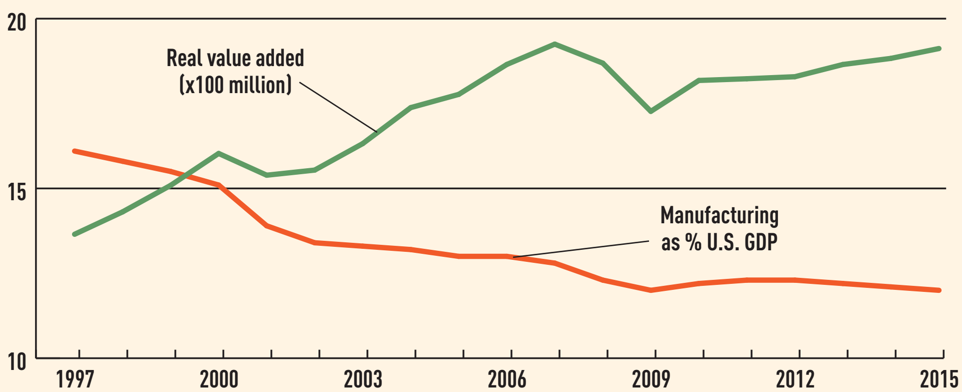
Manufacturers also outsource services—everything from unskilled labor like cafeteria operations and equipment maintenance to professional jobs like product design, and even management. Some companies, like DHL, not only manage supply chains, but deliver materials to machining stations on the factory floor as well.

These were once all factory jobs and would have been counted as factory employment. Today, although they still depend on manufacturing, they are classified under such headings as information, food services, and repair and maintenance. This greatly understates the importance of manufacturing in the U.S. economy.

Manufacturers have long bundled their products with services, such as contracts covering maintenance and repair. Over the past decade, however, some vendors have begun to translate improvements in software and sensors into more compelling value-added services. For example, the bearings maker SKF will remotely monitor their products even after installation to detect problems before they force a work stoppage. Other companies promise to operate machinery and facilities remotely to improve their performance.

According to an estimate by the Organization for Economic Cooperation and Development, services added one-third of the total value of products sold by U.S. manufacturers in 2011. Few of those services would be captured in manufacturing statistics. ■

AS MANUFACTURING RISES, ITS SHARE OF GDP FALLS



Source: https://www.bea.gov/industry/gdpbyind_data.htm

Between 1997 and 2015, manufacturing output as measured by real value added rose by 40 percent. That may sound impressive, but gross domestic product more than doubled over the same period and the contribution of manufacturing to the U.S. economy declined 25 percent.

MANUFACTURING WITHOUT FACTORIES

Manufacturing is not only bigger but also more important to the economy than most people think. In 2016, it accounted for nearly 12 percent of U.S. gross domestic product and two-thirds of all goods and services exported by the United States. By itself, American manufacturing would rank as the world's eighth largest economy.

U.S. manufacturers make valuable products. This is true of all developed nations. The United Nations Industrial Development Organization estimated that only 63 million of the world's 367 million manufacturing jobs were in developed nations, but those workers added two-thirds of the final value of all manufactured goods.

To take one example, a highly cited 2011 analysis led by Kenneth Kraemer of University of California, Berkeley, found that for an iPad that sold for $300 in the United States, Apple retained $90 in profit. After Apple, the biggest winners were South Korea and Taiwan, which supplied the chips for the device.

Compare that to the value added by factories in China that assembled the iPad. Those factories captured only about $10 for each iPad assembled.

The study's authors found similar patterns for most branded products assembled in China.

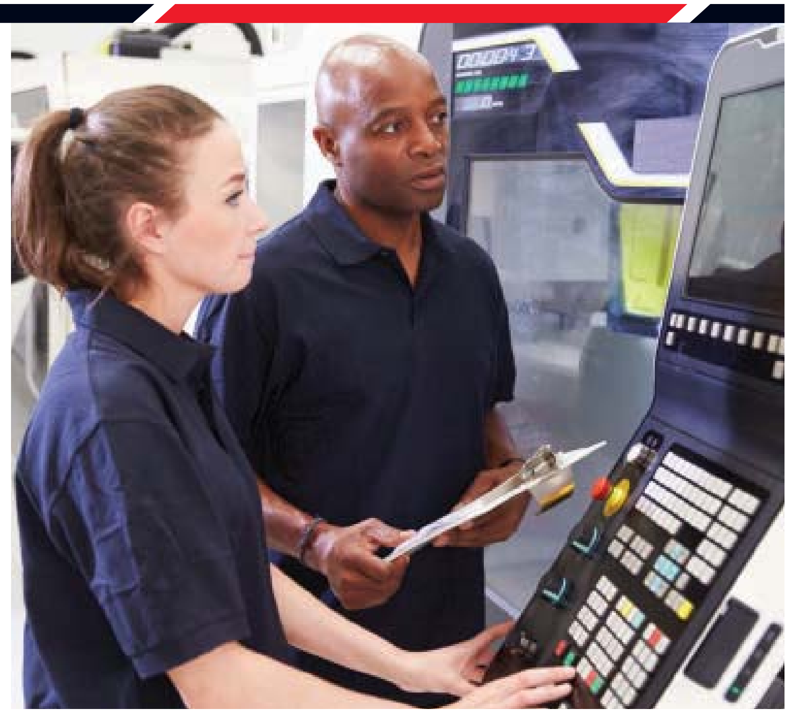
High-value production supports other benefits. Manufacturers support about half of all research and development conducted in the United States, and more than two-thirds of private R&D. To be sure, about one-third of that private R&D is spent by pharmaceutical companies (largely for clinical studies), but aerospace, chemicals, computers, electronics, and motor vehicles also made significant contributions. All told, U.S. manufacturers plow about 11 percent of sales back into R&D.

Research and development supports better design and engineering, which add the majority of value to high-value products and the industrial processes needed to make them. Some argue that moving production overseas isolates design engineers from the process knowledge needed to make high-quality, low-cost products. Still, factoryless firms such as Apple, Nike, and Google continue to succeed by developing innovative product designs while letting manufacturing partners plan the production process. ■

WHY MANUFACTURING MATTERS

Percentage of GDP	11.7
Percentage of workers	8.5
Average salary	$26.36/hr
Percentage of U.S. engineers employed	>30
Value added	$2.2. Trillion
Exports	$1.1 Trillion
Percentage of goods & services exports	66
Foreign direct investment	$1.223 Trillion
Percentage all U.S. R&D	49
Economic activity/ $ manufacturing sales	1.35-1.5

Sources: Bureau of Labor Statistics, Bureau of Economic Analysis, Bureau of Census, National Science Foundation, industry studies.



BLUE COLLAR BLUES

Manufacturing once promised good wages, benefits, and lifetime employment to Americans with a strong work ethic and modest skills. That contract has changed, but opportunities still exist for people with the right skill sets.

The U.S. manufacturing sector lost 5 million jobs—4 million of them in production and nonsupervisory positions—between 2000 and 2016. Yet it still employs 8.5 percent of the nation's workforce, twice as many as construction. Manufacturing workers are well-compensated, and 92 percent qualify for employer health insurance, according to the Kaiser Family Foundation. Their wages and benefits averaged $81,289. That's 20 percent higher than the average of all nonfarm workers, according to the U.S. Bureau of Economic Analysis.

Yet many manufacturing-related jobs are not counted due to outsourcing. Those jobs range from design and engineering to maintenance and IT. Since businesses often outsource work to cut costs during recessions, this exacerbated the employment drop after 2008.

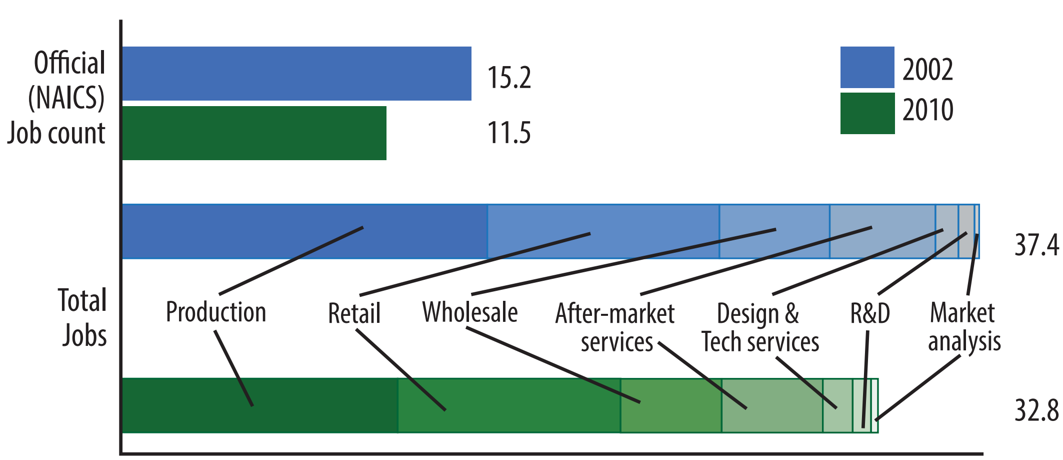
Researchers struggle with trying to figure out the full extent of manufacturing jobs. In 2015, for example, The Brookings Institution estimated the number of people employed by the manufacturing value chain, which stretches from manufacturing through sales and service. Their estimate is three times larger than that of workers classified as manufacturing.

Of course, many of the people counted in the manufacturing value chain are retail and wholesale workers who handle both domestically produced and imported goods. Nor does the Brookings study capture factoryless firms, or the hundreds of thousands of temporary workers that manufacturers now employ.

Yet Brookings found that in 2010, in an economy shaken by a massive recession, jobs in design and technical services, R&D, and market analysis rose by roughly 376,000 employees. Although aftermarket services declined, the growing trend to bundle services with products (made easier by the Internet of Things) is likely to bounce back very strongly in the future.

Brookings also concluded that manufacturers are hiring people with the right skill sets. That extends to the factory floor. Today, more automated plants need workers who combine computer savviness with human judgment. In a 2015 Deloitte Consulting and Manufacturing Institute survey, 80 percent of manufacturers reported a moderate or serious shortage of qualified applicants. ■

MANUFACTURING JOBS: OFFICIAL DATA VS. VALUE CHAIN ESTIMATE



Source: Innovation and Manufacturing Labor: A Value Chain Perspective, *Brookings Institution*

According to official statistics, manufacturing employment shrank by almost 25 percent between 2002 and 2010. Yet losses among all workers, from researchers through retailers, who owe their jobs to manufacturing were half of that, and some professions, such as design and market analysis, even grew despite the recession.

THE HIGH COST OF FREE TRADE

Econ 101 students learn that free trade improves everyone's welfare: Both consumers and manufacturers gain access to better goods at lower costs. If nations concentrate on areas where they have a comparative advantage, theory states, their exports will generally balance their imports, and workers displaced in one industry can find well-paying work in another.

That theory came under attack during the 2016 election campaign. Donald Trump and Bernie Sanders both argued that trade deals gave other nations unfair advantages. A growing number of economists agree.

First, the data: U.S. manufactured exports quadrupled over the past 25 years, yet its share of world trade fell and imports—especially from China—rose dramatically.

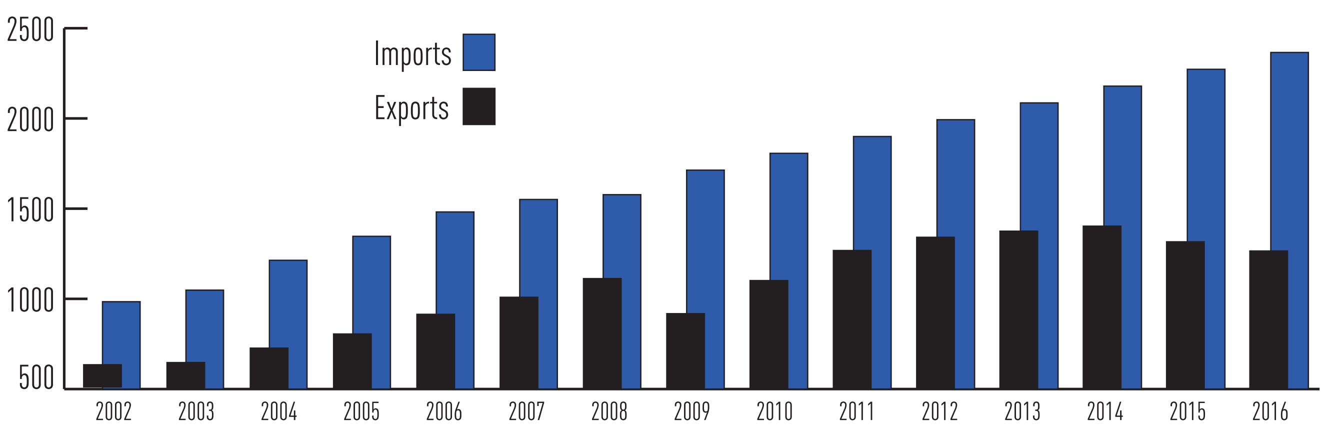
Not all imports have the same impact. Most Mexican imports are labor-intensive parts that U.S. factories incorporate into products to keep them competitive. Manufacturers worry more about China. Since China joined the World Trade Organization, giving its exports duty-free entry into the United States, more than 70,000 factories have closed and 5 million manufacturing workers have lost jobs.

The Information Technology and Innovation Foundation suggests this is no accident. The Chinese government limits imports through high tariffs as well as policies that force potential exporters to build plants in China. Poor intellectual property protection and preferences for Chinese-owned companies often put foreign firms at a disadvantage in the China market. Meanwhile, other nations have accused the People's Bank of China of currency manipulation in order to subsidize Chinese exports.

The ITIF says today's open markets are vulnerable to exploitation from countries that use state power to build exports and protect against imports—what the federation calls modern mercantilism. In fact, in 2014, it developed an index that ranked countries by mercantilist policies. China came out on top (57.5), followed by India (44.6). Germany was near the bottom (7.0) and Japan slightly higher (19.0).

The result of those mercantilist policies on some regions of the U.S. has been dire. David Autor, a labor economist at MIT, has said Chinese exports depressed entire manufacturing-oriented communities, leading to widespread unemployment and lower wages as local markets failed to adjust to this onslaught. ■

U.S. MANUFACTURING EXPORTS GROWING (BUT NOT AS FAST AS IMPORTS)



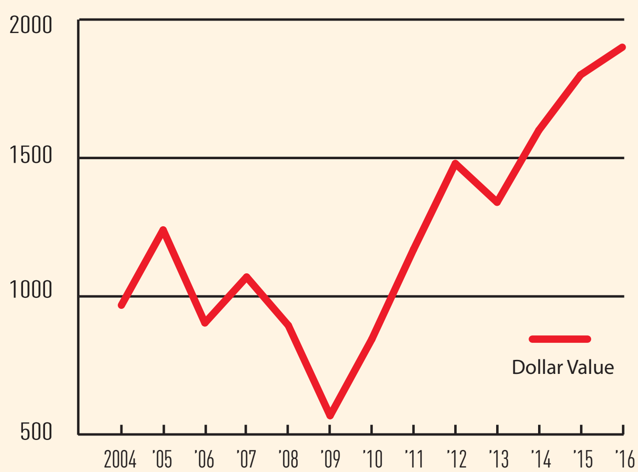
Source: U.S. Bureau of Census

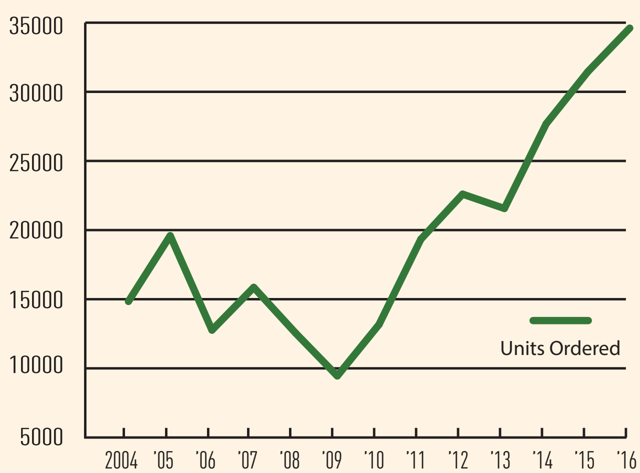
HOW MUCH AUTOMATION?

Much ink has been spilled about the threat to jobs posed by robots and advanced automation. But the evidence suggests the effect to date has been limited.

A recent study by the Boston Consulting Group identified 1.4 million industrial robots used worldwide. Three quarters of them are found in just four industries: transportation equipment; computers and electronic products; electrical equipment, appliances, and components; and machinery. In addition, 80 percent of robots are sold in only five countries: China, Germany, Japan, South Korea, and the United States.

NORTH AMERICAN ROBOT ORDERS





Source: Robotics Industry Association

Because they are so expensive and inflexible, robots are used today primarily in large factories for such highly structured tasks as welding or the precision placement of electronics. But robot makers are lowering prices, adding safety features that enable robots to work with humans, and developing more intuitive interfaces that make them faster and cheaper to deploy. As a result, Boston Consulting Group estimates that a welding robot costs only $8 per hour to operate (compared with $25 for a human welder).

The consulting firm expects that by 2025, the cost per hour will fall to about $2.

Will that eliminate jobs? Not necessarily. Recently, the McKinsey Global Institute looked at 2,000 discrete workplace tasks to assess their automation potential. Jobs involving collecting data, processing data, and predictable physical work were most vulnerable. About 60 percent of manufacturing jobs fell into that category (well behind accommodation and food services at 73 percent).

Of course, many factories do not do predictable physical work. For example, Marlin Steel in Baltimore responded to cheap Chinese imports by doing more custom work. While robots weld its specialized baskets, humans design them and manage the logistics. Overall, employment has doubled, but the mix of workers has changed.

In fact, cheaper, more capable robots working with people might improve the economics of domestic production. It happened in the 1990s, when banks began deploying ATMs. This reduced operating costs so much, banks opened new branches and hired more tellers. Manufacturing workers are hoping the same lightning strikes twice. ■

ORGAN BANKING

Mechanical engineers have the know-how to push back the boundaries of cryopreservation of human tissues.

BY YOED RABIN AND JEDEDIAH LEWIS

Surgeons rush to make the best of a tragic situation, recovering organs from the victim of a tragedy so they can be readied for transplantation, saving a waiting patient's life. It's an extraordinarily delicate situation, and time is the enemy.

At present, organs can be maintained outside of the body for hours at most and often must be matched to recipients far from the site of donation. Surgical teams and waitlisted patients are on call around the clock to receive organs flown in by jet or helicopter. Those time constraints mean that opportunities to match donated organs with the best recipients are profoundly limited. Today in the United States, some two-thirds of hearts from eligible donors go untransplanted, and 20 percent of kidneys must be discarded.

In the United States, around 30,000 organs find recipients each year—a fraction of the need. Roughly 120,000 patients are currently awaiting an organ transplantation, and the number of patients on official transplant waitlists is dwarfed by true potential of transplantation. Millions worldwide suffer from diseases for which transplantation is the gold-standard treatment. Some peer-reviewed articles suggest that organ transplantations could avert more than 30 percent of all U.S. deaths.

The inability to preserve human tissues for long periods outside the body impacts other areas of medicine as well. For example, research in areas such as tissue engineering and drug discovery is hampered by the limited shelf life of organs and tissue samples. The long-term preservation of ovaries and ovarian tissue—an approach that has succeeded experimentally—is another area where new technology could promote human well being.

For these reasons, the long-term preservation of organs and tissues is a major priority in biomedical engineer-

ing research. While slowing the natural degradation of biological materials can be accomplished by mild cooling to hypothermic conditions, only extremely low temperatures—far below the natural freezing point of biological solutions—can facilitate long-term storage, in a process generally known as cryopreservation (*cryo* means ice-cold in Greek). To develop the science and technology of cryopreservation, researchers are tapping expertise from core engineering areas such as heat and mass transfer, solid mechanics, materials science, nanotechnology, computer modeling, information technology, and microelectronics—with prominent leadership by mechanical engineers.

To further explore how engineers from various disciplines can offer a broader and improved set of tools to tackle preservation challenges, ASME and the Organ Preservation Alliance are co-organizing the Summit on Organ Banking through Converging Technologies in Boston, Mass., this August. (See sidebar on page 49.) In addition, the new Advanced Regenerative Manufacturing Institute, launched late last year with $300 million of funding from the Department of Defense, will focus on logistical challenges in tissue engineering, including the extension of shelf-life for engineered tissue constructs.

The shortage of organs for transplantation is a public health crisis. The gap between the current state of the art and the technology needed for cryopreservation is one that an orchestrated effort between cryobiologists and mechanical engineers can bridge.

Preserved in glass

Time is a critical factor for organ transplants. As soon as tissues are removed from the body, they undergo natural degradation which causes their structure to disintegrate and their cells to die. The only way to stop the clock on cell death is to trap the biological material in a solid-like state in cryogenic conditions.

Techniques for successful cryopreservation have been developed over the past five decades for several tissue types, with some dramatic advances being made in recent years. At present, however, successful applications are generally related to small specimens, ranging from micrometer-scale cell clusters such as stem cells to millimeter-scale tissues like corneas. In humans, researchers have been able to cryopreserve larger specimens only for tissues such as heart valves where the mechanical function, rather than the inherent biological functionality, is of higher priority.

It's important to note that cryopreservation is different, and more difficult, than simple freezing, since freezing involves the formation of ice crystals that can mutilate cell membranes and other important cell structures. Instead, effective cryopreservation of large structures requires trapping the biological material in an amorphous, glassy state in a process known as vitrification. While the concept of cryopreservation via vitrification is almost a century old, its application to large-size specimens is only now on the verge of becoming a practical reality.

In order to achieve vitrification, cryobiologists introduce glass-promoting solutions known as cryoprotective agents, or CPAs, into the tissue. CPAs exhibit an exponential increase of viscosity when the temperature decreases rapidly.

To achieve vitrification, tissues are permeated with CPAs and then quickly cooled to very low temperatures over a time period shorter than it takes for crystallization to occur. Below a threshold known as the glass transition temperature, the CPAs become so viscous that the specimen can be considered solid for all practical purposes, yet no ice crystals are present that might damage the cell structures. Rapid rewarming is also required when the material is recovered from cryogenic storage, to eliminate the

The kidney on the right was cryopreserved in a glassy state, while the one on the left was frozen.
Photo: Gregory M. Fahy

possibility of crystallization when the CPA regains fluid behavior while the temperature is still below the freezing point.

It shouldn't be a surprise that fundamental thermal engineering is paving the road for the design and optimization of cryopreservation protocols. One example of the contribution of thermal engineering is in the thermal characterization of new CPAs and biocompatible materials developed by biologists and chemists.

Engineers have found, for instance, that the thermal conductivity of a crystalline dimethyl sulfoxide—one of the most common ingredients in CPA cocktails—is up to an order of magnitude higher than that of its amorphous state. This means that it is much more difficult than originally anticipated to cool the center of a large organ, and to achieve the high cooling rates necessary for vitrification. It follows that without the detailed knowledge of the thermal conductivity, a thermal engineer would not be able to help the cryobiologist in correlating cryopreservation success with the thermal conditions that led to it.

Cryopreservation success is not only about temperatures and cooling rates, but more importantly about the thermal history that the specimen experiences. For example, two nearly identical tissue samples that were exposed to different thermal histories along the path to cryogenic storage may have radically different propensities to form crystals. That path dependency, along with the thermal properties and geometry of the tissue, the CPA cocktail used, and even the kind of container that holds the sample, adds virtually endless complexity to the analysis of experimental systems and computational models—it represents a major hurdle in developing guidelines to assist cryobiologists wishing to preserve tissues.

The concept of cryopreservation via vitrification is almost a century old, but its application to large-size specimens is only now becoming practical.

Cooling and stress

As researchers push the boundaries on the ability to cryopreserve bulky tissues and large organs, a new thermal challenge emerges. Rapid cooling can potentially give rise to dangerous thermomechanical stress driven by the tendency of the material to contract with temperature. That stress can surpass the strength of the material and cause structural damage or even fractures. Structural damage can be evident even in milliliter-size specimens.

More gradual cooling is one possible solution, and researchers still can achieve vitrification in samples that are cooled slowly by increasing the concentration of CPAs. But that poses another danger: At high concentrations, CPAs are toxic, and the longer a metabolically active tissue is exposed to the chemicals, the greater the damage the CPAs cause.

As the cryopreservation process progresses, the toxicity of the CPA wanes with the decreasing temperature of the specimen. But with a decrease in temperature, there is a need for an increase in the CPA concentration to suppress the harmful effect of water crystallization.

Another approach is to increase in CPA concentration gradually, concurrent with the decrease in the temperature of the sample. However, CPA concentration is only one parameter, where the resistance to CPA perfusion into the tissue only increases with the increased viscosity as temperatures drop, further affecting CPA permeation through cell membranes and other barriers.

The three research goals to achieve cryopreservation—promoting vitrification, reducing toxicity, and averting structural damage—appear to be working against each other. Fortunately, mechanical engineers have the tools to potentially solve the trilemma, based on engineering analysis techniques and optimization methods.

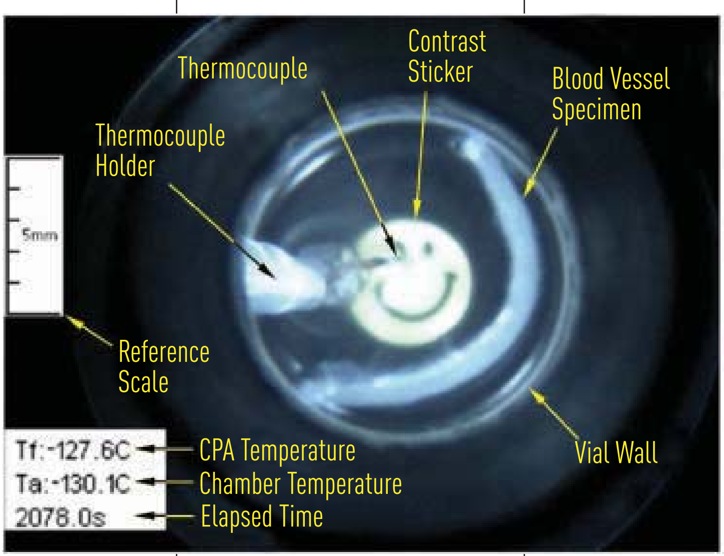
One cutting-edge approach that lowers the barriers to solve the trilemma is to develop synthetic ice modulators, or SIMs, that impede the formation and growth of ice nuclei and crystals. Small quantities of SIMs could reduce the concentrations of other, more toxic ingredients in the CPA cocktail and enhance the stability of the vitrified tissues. Key mechanical engineering challenges with SIMs include measuring their physical properties, investigating their effect on the thermal history and the resulting mechanical stress, developing mathematical models to explain ice modulation, and exploring biotransport effects at the cellular level.

Rapidly cooling large specimens can potentially give rise to dangerous effects driven by the tendency of the material to contract with temperature.

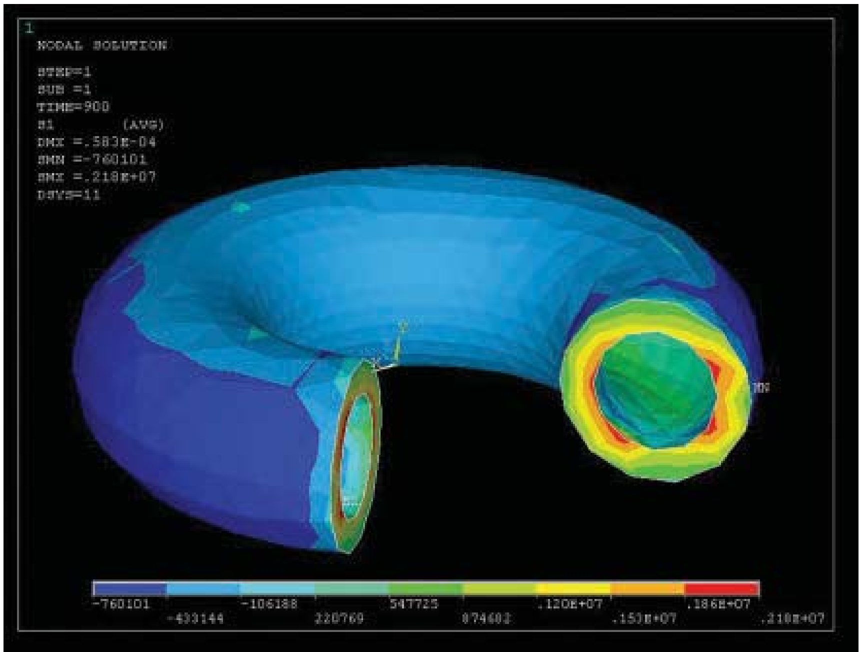
The competing needs for reducing toxicity, preventing ice formation and growth, and reducing mechanical stress complicate the process of recovering the specimen from cryogenic storage. The process of rewarming requires a very high rate of temperature change, which risks further mechanical stress. One concept for solving the trilemma during rewarming involves heating the tissue internally throughout the sample rather than from the outside in. While microwave heating—similar to food thawing—could create the desired internal warming, nano heaters can help organ recovery from cryogenic storage.

A very attractive concept called nanowarming is accomplished by infusing the tissue with magnetic nanoparticles prior to vitrification. Upon demand, the cryopreserved tissue is then subjected to an oscillating electromagnetic field in the radiofrequency range, which excites the nanoparticles and causes them to heat up. However, there are many engineering challenges remaining, ranging from the synthesis of the particles themselves to their uniform dispersion within the tissue to modeling and controlling the process in order to meet the desired rewarming outcomes.

Clearly, mechanical stress and structural integrity play key roles in cryopreservation success, during both as the specimen



This image shows a successful vitrification of a blood vessel in controlled conditions.
Image: Yoed Rabin, Carnegie Mellon University.



A solid-mechanics model simulates a blood vessel undergoing vitrification. *Image: Yoed Rabin, Carnegie Mellon University.*

cools and as it recovers from cryogenic storage. The cryobiology community has known for decades that it needed better solid-mechanics knowledge and tools to characterize structural damage suffered by cryopreserved samples and to devise means to prevent it. At present, however, the area is still relatively uncharted.

It is not just that the mechanical behavior of biological materials undergoing vitrification has not been fully understood, but also that only a small range of measurement instrumentation has been devised and a limited number of analysis techniques have been formulated. Preserving structural integrity represents an emerging engineering area in cryopreservation research, which becomes more critical with the increasing size of the organs to be preserved.

Interdisciplinary effort

Cryobiologists and medical researchers cannot do this alone. Considerably more engineering contributions are needed as part of an organized, interdisciplinary effort in order to make organ banking a practical reality.

Engineers are needed to help foster the emergence of organ banking through work in areas beyond cryopreservation. It will take engineers to design ways to better protect biological material between recovery and transplantation. It will be engineers who develop the hardware needed at every step of the road between the donor and the recipient.

For example, engineers have been developing the tools undergirding the Internet of Things and Big Data that will enable the rise of a more deliberate approach to organ banking. From the donor to the recipient, Big Data tools will elevate the ability to monitor and control the history of the organ. That history includes organ preparations and handling, short-term organ storage during shipping, cryogenic storage in biobank facilities, organ reconditioning, and even the history of the organ after transplantation, as transplantation success is evaluated over an extended period of time. By incorporating Big Data tools, many parameters can be correlated with patient recovery, such as the quality of donor-recipient matching, specific clinical procedures, and the history of the organ.

Further into the future, those computation tools may serve a global infrastructure for organ banking. The high-volume data traffic that will fuel that global system calls for the development of smart, networked sensors with the ability of onboard compilation and local evaluation. Such sensors will, in essence, place cryopreserved organs into the Internet of Things, monitoring a wide array of critical data including temperature, stress, toxicity, and metabolic activity, without affecting the integrity of the organ, clinical procedures, and biocompatibility needs.

The engineering approach

When it comes to developing lifesaving medical technology, we often resort first to biologists and medical researchers. Their approach to research is typically geared

Heating tissue internally throughout the sample can help organ recovery from cryogenic storage.

toward hypothesis-driven and diagnostic studies. While the diagnostic approach may yield a quick response to burning questions, it is often prone to trial-and-error investigation and sometimes scattershot progress.

In a field such as cryopreservation that has real and urgent needs, it makes sense for there to be diversity in research cultures, where the engineering approach can make special contributions. The engineering approach can integrate predictive tools that are rooted in physical measurements, mathematical modeling, and computation power. By applying a mechanistic approach, complex tissues and cryopreservation processes can be understood by examining the workings of their individual parts and the manner in which they are coupled. The engineering approach requires a higher upfront investment, but it provides a high return in the long run, especially as computer modeling and simulation techniques can gradually replace a significant portion of physical experiments.

Cryopreservation of organs, critical native tissues, and engineered tissue constructs is the key means to meet one of the largest public health challenges of the 21st century: the shortage of organs and tissues for transplantation. But it is not a challenge that can be met by biologists and medical researchers alone. Engineers—especially mechanical engineers—have demonstrated their invaluable contribution towards making tissue and organ banking a reality, with an ever-expanding role, as medical progress occurs on the boundaries of life sciences and engineering technology. **ME**

YOED RABIN is a professor of mechanical engineering, professor of biomedical engineering, and the director of the Biothermal Technology Laboratory at Carnegie Mellon University in Pittsburgh. **JEDEDIAH LEWIS** is the president and CEO of the Organ Preservation Alliance and the executive board chair of the Organ and Tissue Preservation Community of Practice at the American Society of Transplantation. To learn more about the organ banking challenge, visit **organpreservationalliance.org**. To register for the Organ Banking Summit, go to **obs2017.org**.

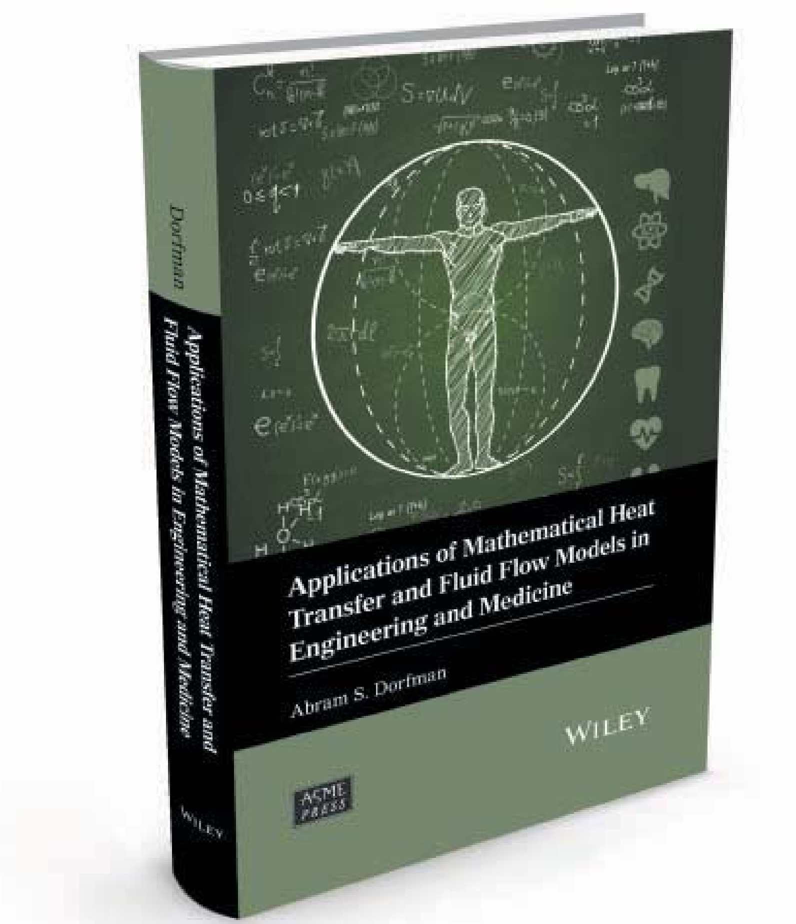
A nonfrozen rat liver supercooled to -6 °C sits in preservation solution within a perfusion system.
Image courtesy: Wally Reeves, Bote Bruinsma, Martin Yarmush, Korkut Uygun, Harvard University/Massachusetts General Hospital

The engineering approach requires a higher upfront investment, but it provides a high return in the long run.

Summit on Organ Banking

The upcoming Summit on Organ Banking through Converging Technologies (**obs2017.org**) is a venue for bringing diverse research approaches together. Held across multiple sites at Harvard Medical School and around Boston, the summit will bring together engineers and scientists with a broad area of research interests to explore ways to apply new platform technologies to the grand challenge of organ banking. Many of the researchers come from fields outside of cryopreservation but have built complementary engineering expertise that can be applied to make breakthroughs.

The summit is also suited for engineers who have little or no background in cryopreservation and biobanking, since it will provide a crash course on the topics and an array of potential collaborators eager to make cross-disciplinary strides in these emerging areas of research.



FEATURED

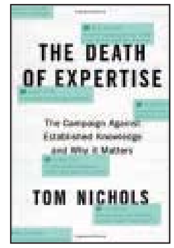
APPLICATIONS OF MATHEMATICAL HEAT TRANSFER AND FLUID FLOW MODELS IN ENGINEERING AND MEDICINE

ABRAM S. DORFMAN

ASME Press Books, Two Park Ave., New York, NY 10016. 2017.

The power of mathematics is that it enables problems from fields as varied as engineering and biology to be considered from one point of view using similar models. Dorfman's book, co-published with John Wiley & Sons, presents methods in fluid flow and heat transfer that have been developed and put into use over the last fifty years. He delves into the applications of contemporary conjugate heat transfer models in various industrial and technological processes, from aerospace and nuclear reactors to drying and food processing. He also looks at two recently developed models in fluid flow: the similar conjugate model for simulation of biological systems (including flows in human organs) and applications of the latest developments in turbulence simulation by direct solution of Navier-Stokes equations.

456 PAGES. $120; ASME MEMBERS $96. ISBN: 978-1-119-32056-2

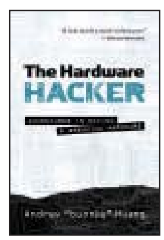


THE DEATH OF EXPERTISE: THE CAMPAIGN AGAINST ESTABLISHED KNOWLEDGE AND WHY IT MATTERS

Thomas M. Nichols
Oxford University Press, 198 Madison Ave., New York, NY 10016. 2017.

Nichols, a professor at the Naval War College and at the Harvard Extension School, admits from the outset that his title is slightly overstated. "While expertise isn't dead, however, it's in trouble," he wrote. "The United States is now a country obsessed with the worship of its own ignorance." He digs into the challenges to engaging in an informed debate on technical subjects in an era when people are used to diagnosing themselves on WebMD or briefing themselves with a crowd-sourced Wikipedia article. Even universities are failing us, Nichols contends, as financial pressures transform academia into a "customer-focused" business. But Nichols doesn't spare the experts, who need to remember that they are servants of the democratic system and must find a way to engage the masses.

272 PAGES. $24.95. ISBN: 978-0-1904-6941-2



THE HARDWARE HACKER: ADVENTURES IN MAKING AND BREAKING HARDWARE

Andrew "bunnie" Huang
No Starch Press, 245 8th St., San Francisco, CA 94103. 2017.

Open-source software and computer hacking have become common ideas of the Digital Age, but Huang has spent his career pushing those concepts into the physical world. Huang contends that hardware has no secrets, and his book attempts to show the truth of that statement. An MIT-trained engineer, Huang has explored the factories and markets of South China looking at the way the commoditization of parts has created the opportunities for small companies or even individuals to create products such as laptop computers or Internet of Things-empowered devices. "Some of the greatest insights I've had into improving a product," Huang wrote, "have come from observing technicians at work on a line and seeing the clever optimization tricks they've developed after doing the same thing over and over for so long."

416 PAGES. $29.95. ISBN: 978-1-5932-7758-1

In This Issue

Global Gas Turbine News

Volume 57, No. 2 • May 2017

ASME INTERNATIONAL GAS TURBINE INSTITUTE

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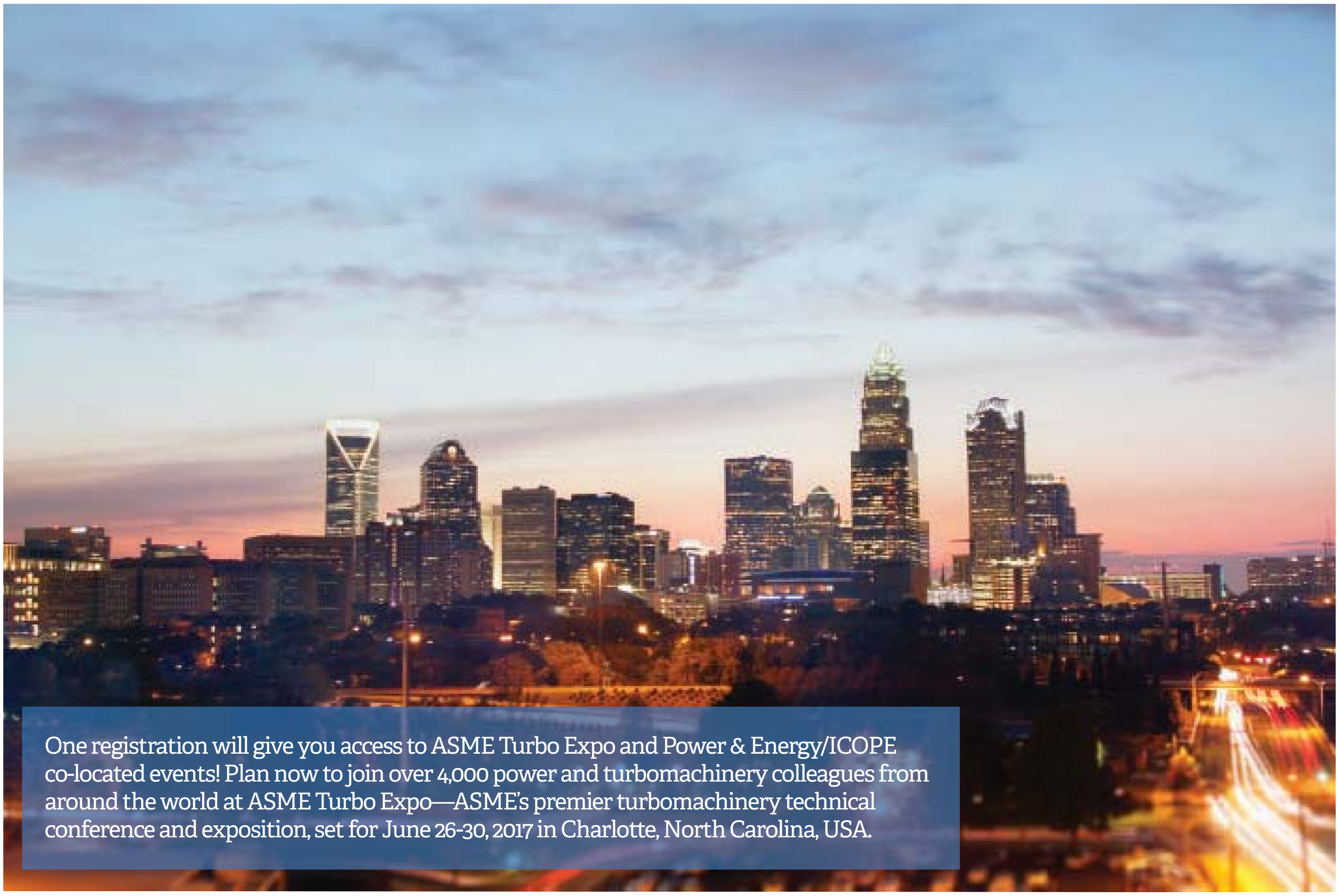

One registration will give you access to ASME Turbo Expo and Power & Energy/ICOPE co-located events! Plan now to join over 4,000 power and turbomachinery colleagues from around the world at ASME Turbo Expo—ASME's premier turbomachinery technical conference and exposition, set for June 26-30, 2017 in Charlotte, North Carolina, USA.

Charlotte

Don't Miss The Big Event. Register Today for ASME Turbo Expo 2017.

Now in its 62nd year,

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Networking Events
If you are a woman in turbomachinery, come have dinner on Tuesday night.

If you are a student or early-career engineer, network with your peers at the mixer on Wednesday night.

Join your colleagues for complimentary light refreshments during the welcome reception at the NASCAR Hall of Fame.

The casual atmosphere of these events is ideal to catch up with friends and meet the thinkers from around the world who are shaping the future of turbomachinery and the power industry.

The **advance program** is online, which allows you to look over the technical sessions and decide now which ones you would like to attend. See if there is anything new that sparks your interest—perhaps a new technology that could be of great significance in the future.

For a small additional registration fee, consider attending one of the six **Pre-Conference Workshops.**

Plan now to join 3,000 turbine colleagues from around the world at ASME Turbo Expo, ASME's premier turbine technical conference and exposition!

Turbo Expo 2017, June 26 - 30
Charlotte Convention Center, Charlotte, North Carolina, USA.
For more information, visit https://www.asme.org/events/turbo-expo

Continued on page 58.

NEW at Turbo Expo

AM3D Day

Presented by ASME Gas Turbine

Wednesday, June 28, 2017

Join us at Turbo Expo for AM3D Day! Learn how additive manufacturing (AM) is impacting the gas turbine industry by:

- Enabling new design and material freedoms
- Shortening the development cycle of gas turbines
- Reducing prototype and testing costs
- Producing parts more easily
- Increasing speed-to-market
- Enabling increased performance through novel design

The day will consist of a plenary session from industry leaders, disciplinary panel sessions, specialized exhibits and a student competition.

Additive Manufacturing Plenary Panel Session:
"Disruptive Technologies and Accelerating Innovation in Gas Turbines – The Role of Additive Manufacturing"

Other disciplinary panels will focus on:

- Processes & Materials for Additive Manufacturing
- Design & Performance for Additive Manufacturing
- Challenges and Opportunities in Using AM for Turbine Cooling
- Combustor/Fuel Injector applications for AM

Who should attend?

- Industry experts in gas turbines
- Suppliers/producers of AM machinery
- Suppliers to the gas turbine industry
- QC/QA Technicians
- AM specialists interested in turbine repair
- Industry experts in AM
- Program and Project Managers
- Designers
- Manufacturing Engineers

Top 5 reasons to be there:

1. Learn about the state-of-the-art AM methods and gas turbine application

2. Gain knowledge by attending focused panels and sessions on AM

3. Create new synergies and identify new opportunities that benefit both gas turbine and AM industries

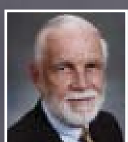
4. Network with leading AM experts and companies to understand the potential value propositions for AM in your own industry

5. Support the future of ASME by attending the ASME student competition on AM3D

Don't miss AM3D Day at Turbo Expo, and stay with us throughout the week to visit companies that are showcasing their additive manufacturing technologies on the expo floor.

"As the Turbine Turns…."

#30 May 2017



Lee S. Langston
Professor Emeritus
Mech. Engr. Dept.
University of Connecticut

A Look at APUs - The Power Behind

Airline passengers are generally well aware of the jet engines that provide thrust power for their flight. But out of their sight and usually out of mind, is the smallest onboard jet engine…the aircraft's auxiliary power unit, acronymed as APU.

The APU is typically hidden in a commercial airliner tail cone compartment and isolated from the rest of the aircraft by a firewall. It evidences itself externally by its small exhaust nozzle which opens out in the aircraft tail assembly. All modern passenger aircraft are equipped with an APU, whose main purpose as an onboard gas turbine is to provide secondary power.

Secondary power consists of generator electricity for avionics and cabin systems, hydraulic needs, compressed air for the environmental control system (e.g. cabin air conditioning) and compressed air to power the starter for the aircraft's main engine. (The main engine can then crossbleed to start other engines.) The APU thus enables the aircraft to operate independently of ground support equipment and without the jet engines running.

Most modern APUs can also be started and operated in flight as needed. Their inflight operation is an FAA certification requirement for all ETOPS flights. (These are Extended-range Twin engine Operation Performance Standards for twin-engine jets on routes with specified diversion times to the nearest airport, in the event of an engine failure and the need for single-engine operation.)

APUs, manufactured by companies like Honeywell and United Technologies, come in a range of sizes, depending on individual aircraft needs. For instance, both of the abundant single-aisle Boeing 737s and Airbus A320s have Honeywell APUs, with a shaft power of 447 kW and a dry mass of 145 kg. The current largest APU is in the twin-aisle, double-decked Airbus A380, a Pratt & Whitney Canada APU at 1342 kW and 447 kg. An extensive itemization of passenger aircraft and their APUs is given by Scholz [1].

Usually on-board aircraft batteries are used to power an electric motor to start an APU. Its gas turbine then powers a load compressor (to supply pressurized air (for, say, cabin air and main engine start) and a generator, via a gear box, for electrical power. The APU uses the same fuel as the aircraft's engines, and according to Croft [2], generally accounts for about 2% of the total fuel burn on a typical mission.

Last November at ASME's IMECE in Phoenix, I visited Honeywell Aerospace, where I was hosted by engineers Joe Panovsky and Fred Borns.

Honeywell 131-9 APU

Cutaway Major Features and Airflow Sequence

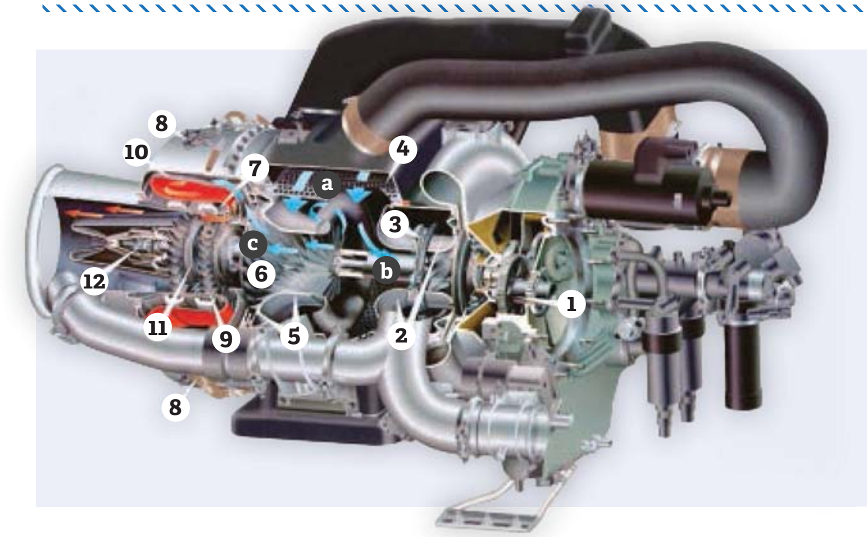


Figure Key

1 Thrust Bearing
2 Load Compressor
3 Inlet guide vane assembly
4 Perforated inlet housing (proprietary inlet design improves performance and acoustics)
5 Engine compressor hub containment
6 High pressure ratio compressor (8:1) for fuel efficiency
7 Cooled first-stage nozzle (improved for longevity)
8 Ten dual-orifice fuel atomizers
9 Full turbine-hub containment for all rotors
10 Effusion-cooled combustor
11 Efficient low-noise, two-stage axial turbine
12 Simple two-bearing, four-wheel rotating group

Air-flow sequence

(a) The air-flow comes in radially through the inlet screen (b) Air is split both ways. To the right is the load compressor that provides the air to the ECS system and starts the main engines (c) The air going left passes through the engine compressor, combustor, and turbine sections (the power section). The power section drives the load compressor and generator.

Figure 1 | Credit - Flight International

Honeywell is the market leader in the APU world, with a current installed base of 35,700 units. They have the APUs (model 131-9, shown in the cutaway in Fig. 1) standard on Boeing 737s and installed in most Airbus A320s. The 131-9 gas turbine is a single spool engine with a centrifugal compressor, a folded combustor and a two-stage axial turbine. This drives a load compressor and an electrical generator through a gear box. My hosts pointed out to me that the unit (Honeywell APU rotor speeds are in the 39,000-63,000 rpm range) will fully contain a turbine-disk failure. (A jet engine company's worst nightmare is an uncontained engine failure, a rare event yet to be successfully prevented [3].)

To get an operant's view, I asked Paul Eschenfelder [4], a retired captain for Delta Air Lines and a U.S. Navy pilot, for his experience with APUs.

He quickly recounted what were the sequence of events for the 2009 US Airways Flight 1549 landing in the Hudson River, after it lost both engines due to bird (geese) ingestion. The first thing the captain did was reach up and hit the APU start button on the Airbus A320. (It had the Honeywell APU shown in Fig. 1.) He also had RAT power (the ram air turbine which drops out of the fuselage for emergency power in the event of a complete engine failure) but the Honeywell APU allowed him to have so much more—more electrical power for radios, instruments and aerodynamic controls.

So despite advances in airplane design, Paul commented that we can view an APU in two lights:

1) It is a device which, on the ground, gives us an environment that passengers demand (cool when hot, hot when cold and electricity throughout).

2) It is a device which may be the back up to the back-ups, but isn't forgotten by the crew, and is viewed as the "ace in the hole" when things get tough.

References

1. Scholz, Dieter, 2015, "An Optional APU for Passenger Aircraft", 5th CEAS Air & Space Conference, CEAS 2015 paper no. 177.

2. Croft, John, 2010, "Power Behind", Flight International, October.

3. Langston, Lee S., 2011, "Gas Turbine Progress through Trouble", Global Gas Turbine News, Mechanical Engineering Magazine, February, p.51.

4. Eschenfelder, Paul 2017, Private Communication, February 13.

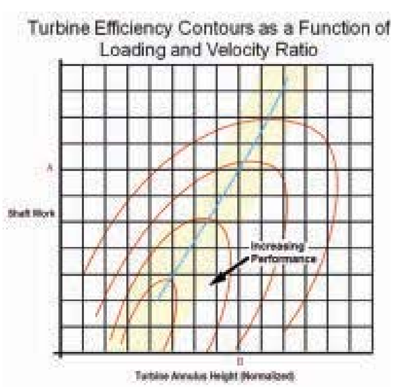
How Many Turbine Stages?

A discussion by Brent A. Gregory (Creative Power Solutions)

Turbine blades all come in the same usual shape with the only seeming variation being varying sizes and either having a rotating shroud or not. However, for similar size Gas Turbines there are sometimes quite dramatic (if not subtle) differences. A good example, that affects the owner/operator directly, is the number of stages in the gas turbine hot section, even though they have similar ratings of MW capacity. Some units produced by various OEM's (Original Equipment Manufacturer) have three (such as GE) stages of turbine, and for a similar output some have four (such as Siemens). Occasionally one might see five stages (as in the case of Alstom). This may be of some cost concern when considering hot gas path replacement or performance-related issues. Other concerns rarely bother the operator, except if clearances or cooling flows are monitored in the form of more performance-related bookkeeping of this particular variable.

The question we wish to ask here is - what determines the designer's choice to select the number of turbine stages for a given design of gas turbine? A reasonable follow up question is who, how or what decides the number of blades in a particular blade row.

Consider this chart:



Looking at the co-ordinates, the shaft work is akin to the "loading" or work performed on the shaft or sometimes by each stage of turbine. The annulus height (a function of the length of the turbine blades), in the case of the Smith chart, is in turn a function of the normalized axial velocity. The chart represents the relationship of the amount of work extracted from the hot gas to that of the blade height (for a given mass flow).

This chart, by Rolls-Royce, shows that the fundamental variables strongly correlate with turbine performance as the independent variable. This can be seen by the red contours in the figure, which illustrate lines of constant efficiency (increasing to the lower left). The highest performance turbines are defined by lower work requirements and slower velocities in the gas path. The fundamental factors determining performance might be relegated to only two factors:

1. Demand on the turbine (shaft work)
2. Axial Velocity (blade height)

It can be seen, therefore, that the blue line represents the peak efficiency line (and hence only one solution) for any given design of turbine.

The chart is significant because:

Given that work is fixed (demand of the compressor and generator [or fan]), and has fixed wheel speed (generally 3,000 rpm or 3,600 rpm for gas turbines in power generation) by the requirement to be synchronous or for aircraft engines the gas generator core speed or the limits of the fan size. Then, since the **work is fixed** (since the work =Mass Flow * Temperature Drop * Cp), the only variables left are the mass flow required to achieve that work and the temperature drop across the turbine.

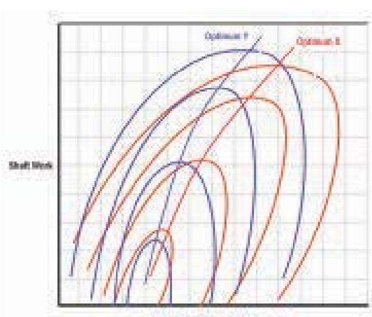
Then the only variable not fixed is the axial through flow velocity (labeled "Turbine Annulus Height") which, from the physics of flow (continuity equation), prescribes the turbine annulus height. This means the designer has few options with which to manipulate a turbine gas path: deviations away from the blue line have a consequence on the blade shape and blade numbers.

Consider an example, the point on the Y-axis at "A" which denotes the required work (given the duty of the compressor and the generator) by the turbine, then the resulting highest performing turbine is prescribed as the point B on the X-axis. Given the annulus area is "fixed" at point B, the designer can fix the maximum diameter, and the annulus area is deduced from simple math (annulus area is a function of the tip and hub diameters).

The maximum diameter is, however, usually chosen at a point where the mechanical designer is comfortable with the maximum stresses on the turbine attachments and the blade length. This is typically the last stage blade.
The aerodynamicist divides the work required on the shaft into several "parts" (where each "part" represents a stage of turbine. If the work A is divided between two stages then the corresponding point on the axis is lowered and the optimum performance curve (the blue line) describes a new point on the Y axis (annulus area). If the work is split among three stages then the points making up the sum of A's value are further lowered and hence also the corresponding points on the X-axis. Note that as the designer invokes this option, each stage of turbine performance increases.

What are the key factors that drive the designer's choice that determine the designer's choice of 2, 3, 4 or even 5 stages of turbine?

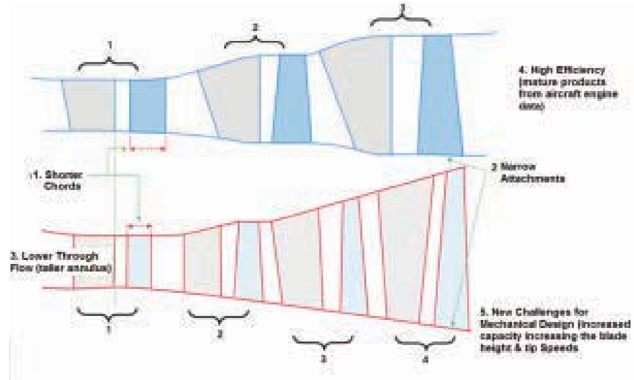
Each OEM then has an optimum set of curves of efficiency, and it is certain they do not line up with one another, consistent with their own particular brand of design. These "brand" characteristics are determined by such things as empiricism derived from previous designs and the results of performance criteria derived from specific tests based on years of research in the academic world and by emerging technologies such as Computational Fluid Dynamics (CFD).



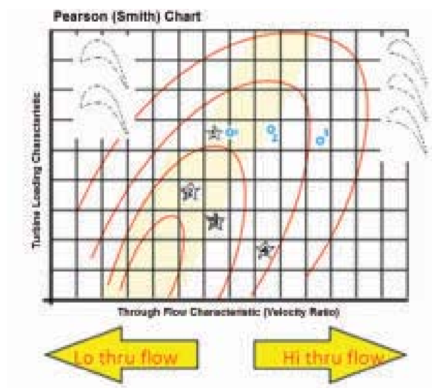
OEM's, typically producing Heavy Frame Gas Turbines (HFGT) together with Aircraft Engines, have a significant advantage when it comes to making technology decisions regarding the components of a Frame Engine, because it increases the range of experience for a given variable—hence, 3-stage designs may even trump the 4-stage design in terms of performance.

Aircraft engine technologies drive new initiatives because of the need to increase firing temperature and dramatically improve efficiency for substantially less weight. Also, the expansion across each stage determined the annulus area so that the optimums implied by the Pearson chart were largely ignored. Developments in aircraft engine gas turbines have forced HFGT OEMS to rethink many historical paradigms.

Below is a typical 3-stage HFGT turbine, and below it is what an equivalent 4 stage would like.



Considered on the Smith chart the stage characteristics for the above turbine schematics are represented in the following chart:



Note the unique features that have forced the OEM's to rethink:

1. Lower "through flow" allows the expansion of each stage to be incorporated in the same diameter as a 3-stage allowing for a retrofit of a 4-stage unit into a similar area.
2. Shorter chords as a result of highly loaded airfoil (more work per blade) technology.
3. Higher loading, reducing airfoil count
4. Attachment areas are refined based on aircraft engine technology.
5. Lower through flow allows for optimized efficiency.
6. Four stage designs do allow for increased performance with larger capacity.

Ref 1. "A Simple Correlation of Turbine Efficiency" S. F. Smith, Journal of Royal Aeronautical Society, Vol 69, July 1965

Ref 2. Improvements to the Ainley-Mathieson Method of Turbine Performance Prediction
J. Dunham and P. M. Came. J. Eng. Gas Turbines Power 92(3), 252-256 (Jul 01, 1970) (5 pages)doi:10.1115/1.3445349

Ref 3. Craig, H. R. M., and Cox, H. J. A., "Performance Estimation of Axial Flow Turbines," Proceedings of the Institution of Mechanical Engineers, Vol. 185, No. 18, pp 407-424, 1971.

"Charlotte" Continued from pg. 52

ASME 2017 Turbo Expo Conference Keynote and Plenary Panel Sessions

MONDAY KEYNOTE: DISRUPTIVE TECHNOLOGIES & ACCELERATING THE PACE OF INNOVATION IN GAS TURBINES

Panelists:

Dag Calafell
Upstream Machinery Chief
Exxon Mobil

Jean-Paul Ebanga
President & CEO
CFM International

Karen B. Florschuetz
President and General Manager
Operations Americas
Dresser Rand, USA and India

Kevin Murray
General Manager, PMC
Engineering & Construction
Duke Energy

Moderators:

Mark Turner
Professor
University of Cincinnati

Paul Garbett
Head of Large Gas Turbine Engineering
Siemens Power & Gas Division

TUESDAY PLENARY: MULTIDISCIPLINARY COMPUTATIONS AND OPTIMIZATION IN GAS TURBINE DESIGN

Panelists:

Dr. Eisaku Ito
Senior General Manager, Business Intelligence & Innovation Department
MHI

Dr. Ingrid Lepot
Research and Technology Manager
Cenaero

Robert Nichols
UAB/AEDC, DOD HPC Modernization Program

Moderators:

Dirk Nuernberger
Siemens Gas Turbines

Mark Turner
Professor
University of Cincinnati

WEDNESDAY PLENARY: DISRUPTIVE TECHNOLOGIES AND ACCELERATING INNOVATION IN GAS TURBINES: THE ROLE OF ADDITIVE MANUFACTURING

Panelists:

Christine Furstoss
Technical Director,
Manufacturing, Chemical & Materials Technologies
GE Global Research

Markus Seibold
Power & Gas Business Lead for Additive Manufacturing
Siemens

Mike Aller
The Consortium for Advanced Production & Engineering of Gas Turbines

Rob Gorham
Director of Operations, National Center for Defense Manufacturing and Machining
America Makes

Thomas W. Prete
Vice President, Engineering
Pratt & Whitney

Moderators:

Karen A. Thole
Department Head of Mechanical and Nuclear Engineering, Professor
Pennsylvania State University

Rich Dennis
Advanced Turbines Technology Manager
U.S. Department of Energy National Technology Laboratory

ASME IGTI Awards & Scholarships

2017-2018 IGTI Student Scholarship

The deadline to submit an application is June 15, 2017.

ASME IGTI will provide up to 20 $2,000 (US) scholarships this school year to qualifying students registered at an accredited university (U.S. or international).

2018 Dilip R. Ballal Early Career Award

Nominations for the 2018 award are due to igtiawards@asme.org by August 1, 2017.

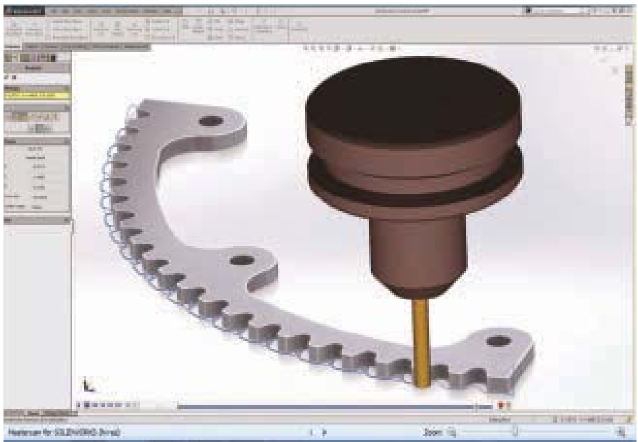
Early Career Awards are intended to honor individuals who have outstanding accomplishments during the beginning of their careers. The recipient of the Early Career Award will be presented with the award at Turbo Expo 2018 in Oslo, Norway.

The ASME R. Tom Sawyer Award

The R. Tom Sawyer Award is bestowed on an individual who has made important contributions to advance the purpose of the Gas Turbine Industry and to the International Gas Turbine Institute over a substantial period of time. The contribution may be in any area of institute activity but must be marked by sustained forthright efforts.

Nomination packages should be received at the ASME Office no later than August 15, 2017, to be considered: igtiawards@asme.org.

For more detailed information on these opportunities, please visit: https://community.asme.org/international_gas_turbine_institute_igti/w/wiki/4029.honors-and-awards.aspx.



MACHINING STRATEGIES

CNC SOFTWARE, INC., TOLLAND, CONN.

USERS CAN DIRECTLY PROGRAM parts in SolidWorks using Mastercam's machining strategies and leading toolpaths. Developed by CNC Software, Inc., the Mastercam 2017 Windows-based CAD/CAM application features analyze toolpaths displaying coordinates, direction, and more when you hover. To simplify your work, Tplanes are now oriented to the SolidWorks geometry that was used to create them. The Mastercam 2017 also now includes a CAD functions menu. Real-time operation data about selected toolpaths can be viewed by selecting the display toolpath statistics option, and category-specific icons are included on the SolidWorks ribbon bar. Expert enhancements are available, including fonts and colors in NC configuration and character coding.

PRODUCT LIFECYCLE MANAGEMENT

SELERANT, MILAN, ITALY

DevEX version 3.3 introduces multi-pack labeling and an updated supplier collaboration portal and document management module to Selerant's product lifecycle management application. The labeling module now includes multi-pack labeling based on reuse of existing source labels developed for individually packaged products. The feature can be used for labeling a carton box containing several identical units, thereby making the process less prone to error. The application also enhances workflow management features to monitor progress of tasks between client and suppliers. In addition, the collaboration portal now provides the possibility to log and trace emails. The document management module now provides the ability to create and manage document mark-up and annotations inside of the application—removing the need to use external mark-up tools.

DESIGN SPACE EXPLORATION

MATHWORKS, NATICK, MASS.

Simulink Design Optimization Release 2016a includes a new sensitivity analysis tool to support design space exploration. The tool allows design engineers using Simulink Design Optimization to interactively conduct design of experiments and Monte Carlo simulations of Simulink models. The sensitivity analysis tool helps perform analysis through Monte Carlo simulations, which enable the exploration of a large design space. The tool helps to interactively specify multiple parameter variations, incorporate a number of standard and custom design requirements, and analyze the results of these simulations graphically and quantitatively. The results of sensitivity analysis can be used to directly influence the design, as well as improve the performance of numerical optimization tasks such as fitting models to test data and tuning models to meet design requirements.

TEST AND ANALYSIS

HBM PRENSCIA, TUCSON, ARIZ.

HBM Prenscia has published version 12.1 of nCode, the company's durability, test, and analysis application. The update provides improvements to the application's DesignLife, GlyphWorks, and VibeSys modules. For instance, VibeSys now offers options to perform modal analysis, which enhances finite element modeling by providing reliable damping ratios outside of the natural frequencies, and DesignLife has new capabilities for vibration-based short-fiber composite calculation, gray-iron analysis, and hot-spot stress extrapolation for weld analysis from solid elements. Improvements to GlyphWorks includes many general usability enhancements and a new capability for inputting vibration datasets.

ADDITIVE MANUFACTURING SUPPORT

DESKARTES, HELSINKI

Expert Series 10.3 is a 64 bit modular application for 3-D color printing, additive manufacturing, and simulation data preparation. The application includes a new solidify command to prepare the most difficult architectural files for 3-D printing with "shrink wrap" method, new support structure command, and 3-D nesting for manufacturing parts. The Dimensions Expert and 3Data Expert Lite modules include the most frequently needed tools for everyday data processing, like 3-D model splitting, connecting, and 3-D text tagging for 3-D printing and additive manufacturing. The splitting functionality with automatic teeth, connector, and clearance generation between the split halves provides for efficient STL model preparation for 3-D printers with smaller work space.

SUBMISSIONS

Submit electronic files of new products and images by e-mail to **memag@asme.org**. Use subject line "New Products." *ME* does not test or endorse the products described here.

ADVERTISER INDEX

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ERDMAN RECEIVES WOO MEDAL

ASME Fellow **Arthur G. Erdman**, professor of mechanical engineering at the University of Minnesota, will receive the 2017 ASME Savio L-Y Woo Translational Biomechanics Medal at a ceremony next month. Erdman specializes in design, and his research includes a number of ongoing projects related to biomedical engineering and medical device design. An ASME member for more than 45 years, Erdman has served in a number of Society positions, including chair of both the Design Engineering Division and Bioegineering Division and the editor of the *Journal of Medical Devices*. Erdman will be presented with the medal at the 2017 Summer Biomechanics, Bioengineering and Biotransport Conference in Tucson.

V&V SYMPOSIUM THIS MONTH

ASME will offer a special symposium this month that will focus on verification and validation and uncertainty quantification. The Sixth Annual ASME Verification and Validation Symposium, to be held from May 3 to 5 at the Westin Hotel in Las Vegas, will cover the latest developments and research in V&V for such industries as bioengineering, nuclear power, medical device design, advanced manufacturing, solid mechanics, fluid dynamics, materials engineering, and power systems.

For more information on the ASME Verification and Validation Symposium, or to register, visit https://www.asme.org/events/vandv. **ME**

STUDENTS CONVENE IN LAS VEGAS FOR E-FEST WEST

ASME's Engineering Festival program engaged engineering students as E-Fest West brought more than 500 students to the campus of the University of Nevada, Las Vegas, in March.

Keynote panelists Dale Dougherty, Eva Hakansson, and John B. Rogers, Jr. at E-Fest West in Las Vegas.
Photo: Mark Skalny

The students came from about 50 universities, mostly across the American West, but also from New York, Florida, Connecticut and Ohio. There were also teams from Lakehead University in Thunderbay, Ontario, and from the Universidad Nacional Autónoma de México in Mexico City.

"E-Fest is an outstanding event," said Paul Stevenson, ASME senior vice president for Student and Early Career Development. On an unseasonably warm day, Stevenson was in the parking lot of the university's basketball complex for the 2 ½ hour endurance course for the Human Powered Vehicle Competition (HPVC).

"The students are so passionate about everything," Stevenson continued. "I've enjoyed coming out here and seeing their ingenuity with their vehicles and their passion for the race. They've been working night and day to make their vehicles run. It's just outstanding."

Other student competitions held during E-Fest West included the Student Design Competition and the ASME Old Guard competitions, plus an informal team-building competition with CDs, cardboard and rubber bands as core components.

In addition to those student competitions, E-Fest West featured presentations from three charismatic keynote speakers: Dale Dougherty, founder and CEO of Maker Media and the creator of Maker Faires; John B. Rogers, Jr., CEO and co-founder of Local Motors; and Eva Hakansson, who is the world's fastest female motorcyclist. Her 19-foot long electric motorcycle, KillaJoule, was a big hit at the event, as were her messages that eco-friendly vehicles can be fast, that engineering is a great career choice for women, and that engineers can build impressive machines in their backyards.

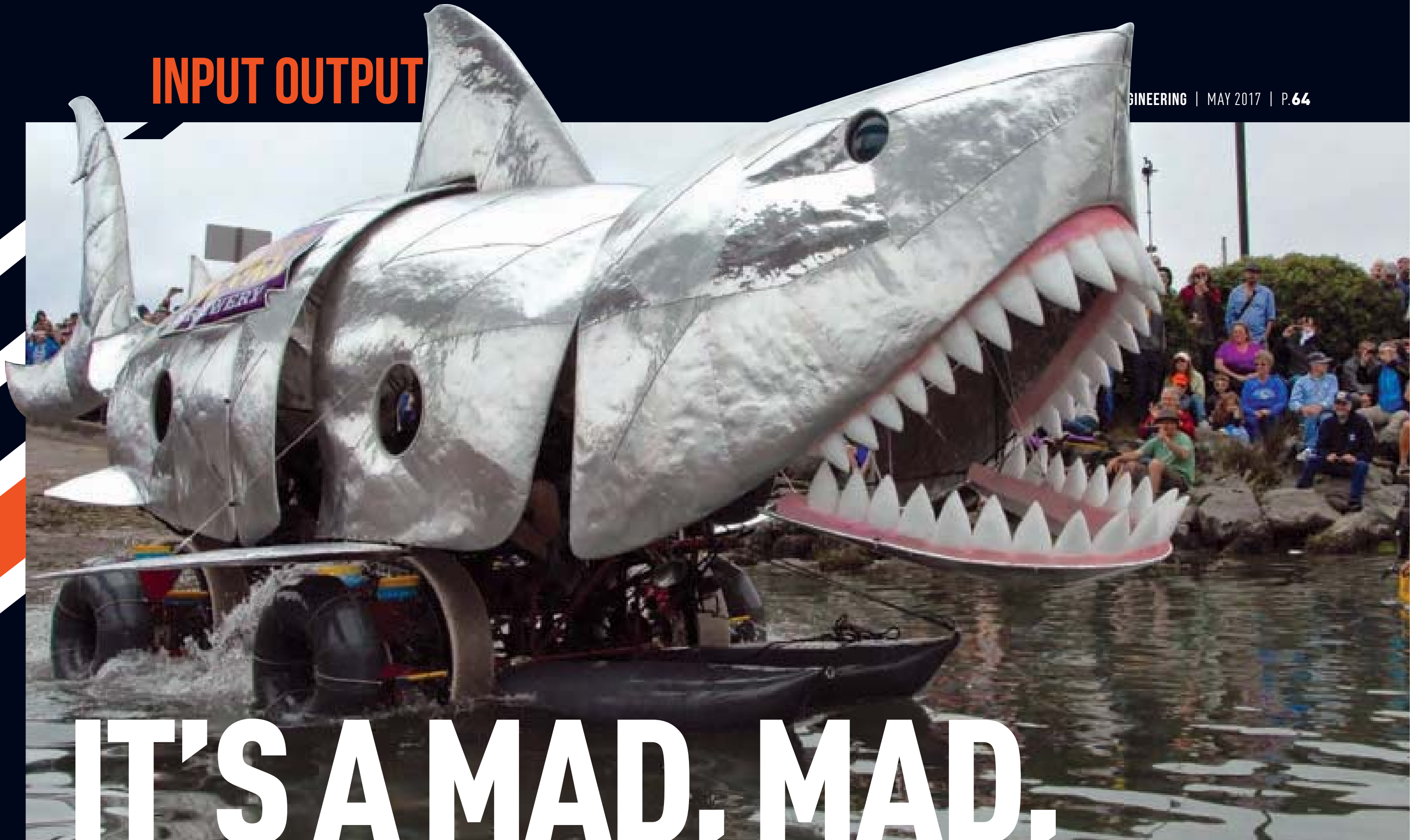
ASME President Keith Roe was thrilled by the students' enthusiasm for hands-on activities.

"It's really inspiring to see these young people get so engaged in engineering," Roe said. "It's a practical side of engineering that makes engineering fun.... I've always felt engineering is a very creative profession. And when you get these people together in these competitions, it makes engineering fun and brings these kids together and it puts a big smile on my face."

Stevenson highlighted the opportunities for students. "There are professional development opportunities, there are opportunities to network with ASME volunteers, as well as with industry," Stevenson said. "It's a great opportunity for students to see what's out there, in their future after graduation."

E-Fest West also included workshops and speakers from event sponsors including Siemens, Autodesk and ANSYS, as well as lightning talks with Dr. Noel Bakhtian, a former senior policy advisor to the White House office of Science and Technology Policy, and with Noel Wilson, creative director of Catapult Design.

E-Fest Asia-Pacific was held at the LNM Institute of Information Technology in Jaipur, India, in early March and E-Fest East was held at Tennessee Tech University in April. **ME**



IT'S A MAD, MAD, MAD, MAD RACE

Ken Beidleman has some advice for anyone looking to finish the Kinetic Grand Championship, a three-day, 50-mile race of human-powered sculptures that travel over sand, dunes, water, hills, and pavement each year in Humboldt County, California.

"Slow and steady," said Beidleman, who has captured six Grand Champion awards and about 13 of the coveted ACE awards, before he stopped counting. "And you better have some damn good engineering."

Each Memorial Day weekend this "Triathlon of the Art World," now in its 48th year, attracts more than 5,000 spectators and about 50 teams that spend much of the year designing, building, preparing, and repairing their moving sculptures.

The race is all about fun and creativity, and a party-like atmosphere prevails. Awards are given for most mediocre, finishing second-to-last, best bribe (yes, participants can bribe judges and spectators with tchotchkes for higher scores), and pageantry, since all participants have to wear costumes that match the theme of their vehicles, be they fish, dragon, insect, or monster.

Beidleman has been mastering winning engineering skills for more than 30 years, and has won 10 KGC awards for best engineering. He helps run the Kinetic Lab, a 5,000-square-foot warehouse in Arcata, the starting point of the race, where select teams build and display their vehicles.

He offers free advice to anyone who hopes to successfully pedal a huge fish, dragon, insect, monster, or other wild vehicle through four towns, a couple of beaches and two bodies of water, all along the often windy and rainy Pacific Coast.

Beidleman's 30-foot great white shark is a good example of winning kinetic sculpture engineering. As each of his four-person team pedals, a 588-gear, three-derailleur transmission system and all-wheel drive helps the 2,000-pound shark climb hills, cruise highways, and traverse choppy water.

The sculpture has two sets of specially designed wheels–a set of custom bicycle wheels that easily traverse pavement and rougher terrain, and another set that supports the sculpture on soft sand. The second set measures six feet wide and has a snow-shoelike surface, with smooth, flexible PVC pipes for traction to help the crew climb up and down dunes. "It took me 20 years to figure that out," Beidleman said.

A series of inflatable pontoons keep the shark afloat, and paddles line the inner edge of the wheel to grip the water when needed.

Steve Cole, an engineer who co-founded Yakima, a cargo rack manufacturer, picked up engineering tips from Beidleman, and now judges the competition.

"Someone can have something that looks perfect and innovative but the first time they go out it will die in the sand," he said. "But there's always a team out there that has designed something that is a step forward in innovative engineering." ME

JEFF O'HEIR a freelance writer based in Huntington, N.Y.