MECHANICAL

ENGINEERING

Technology that moves the world

THE MAGAZINE OF ASME

No. 09 138

MANUFACTURING EVERYWHERE

CLOUD-BASED SERVICES AND UBIQUITOUS SENSORS PROMISE A REVOLUTION IN PRODUCTIVITY.

3-D PRINTER'S TWIST MAY SHAPE HOMEBUILDING

THE RAPID DEVELOPMENT OF DIGITAL and additive manufacturing reaches across industries and disciplines, producing new applications and products on a regular basis. One of the latest applications is in construction, where one startup architectural firm wants to take the bulk out of structures with its novel 3-D-printed wall core. The company expects to begin building a proof-of-concept house in 2017 using completely 3-D-printed components, from a design chosen via a competition.

A NEW SPIN ON VINYL RECORDS

VINYL ALBUMS ARE POPULAR among audiophiles, but the old record-pressing plants are mostly gone. Can 3-D printing help the old-school format get its groove back?

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

A GLUTEN-FREE DINING COMPANION

A START-UP FROM MIT has developed a new sensor to make a gluten-free diet easier to maintain for sufferers of celiac disease.

VIDEO: WHY BIG DATA MATTERS FOR MANUFACTURING

TOMMY GARDNER, chief technology officer at Jacob Associates, discusses the importance of Big Data analytics and the need to have a talented workforce capable of interpreting the data.

NEXT MONTH ON ASME.ORG

VIBRATING CLOTHES POISED TO HELP THE BLIND MANEUVER
A physician who is an assistant professor of rehabilitation medicine has cofounded a new startup to develop a sensing platform that fits into clothing and vibrates to alert visually impaired people of obstacles in their path.

BIOMIMICKING THE VENUS FLYTRAP
A team of engineers at Dartmouth is trying to mimic the behavior of the Venus flytrap using smart materials.

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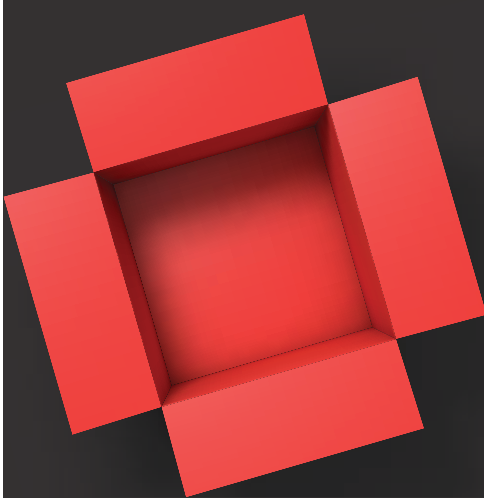
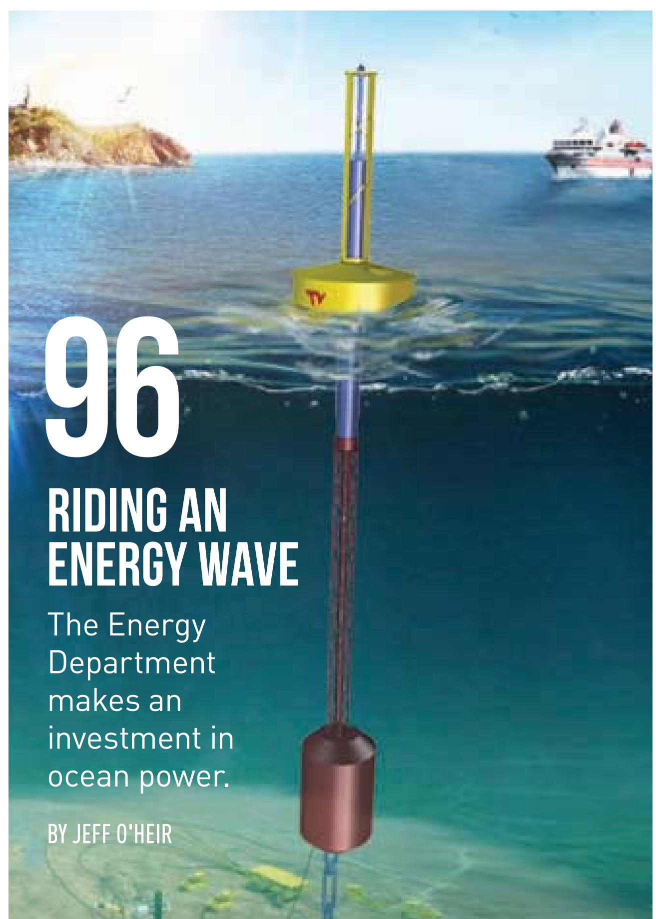
SETTING THE STANDARD



DEPARTMENTS



MECHANICAL ENGINEERING

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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

THE HUMAN CAPITAL OF MANUFACTURING

Even if politics isn't your cup of tea, this year's presidential election has been hard to ignore. Its twists and turns wickedly resemble more the new J.K. Rowling fantasy novel than a noble competition to lead the most powerful country in the world.

One of the salvos being slung from one camp to the other involves opinions on the value of the North American Free Trade Agreement (NAFTA). At its core, the debate centers on whether NAFTA is bad for American manufacturers and workers because it enables cheap-labor countries like Mexico to take manufacturing jobs away from the United States.

Putting politics aside—and that's no small feat given the existing climate—opinions on the causes of middle-income job losses in the United States include both economic forces and, some will argue, technology advances.

A recent column in *The Wall Street Journal* points to two interesting perspectives worth considering. One is an essay in *Foreign Affairs* by Dartmouth economist Douglas A. Irwin, who says that between 2007 and 2009, the United States lost nearly nine million jobs, pushing the unemployment rate up to 10 percent and, seven years later, the economy is still recovering. Even as trade commands broad public support, a significant minority of the electorate—about a third—opposes it. These critics come from both sides of the political divide, but they tend to be lower-income, blue-collar workers who are the most vulnerable to economic change. For these workers, "neither political party has taken their concerns seriously, and both parties have struck trade deals that the workers think have cost jobs," says Irwin.

He argues that trade is but one reason some blue collar workers have lost their jobs. Another is technological advances that impact millions and occurs without enough formal retraining of displaced workers.

Still, "Technological change is far from the only factor affecting U.S. labor markets in the last 15 years," argues MIT economist David H. Autor in a paper published last year in the *Journal of Economic Perspectives*. He notes the deceleration of wage growth, changes in occupational patterns, and dislocations in the U.S. labor market brought on by rapid globalization as the main reasons, but admits that in various ways these are linked with the spread of automation and technology. "Advances in information and communications technologies have changed job demands in U.S. workplaces directly and also indirectly ... altering competitive conditions for U.S. manufacturers and workers."

But "jobs are made up of many tasks," Autor says, and while automation and computerization can substitute for some of them, understanding the interaction between technology and employment requires thinking about more than just substitution. In the end, technology has replaced some traditionally middle-education jobs, but this is the group that is also easiest to retrain.

Engineers have radically simplified manufacturing environments allowing for more autonomous and streamlined operations. But as Autor puts it, "human capital investment must be at the heart of any long-term strategy for producing skills that are 'complemented by' rather than 'substituting for' by technological change." ME

FEEDBACK

Do you think technological advances contribute to unemployment? Email me.

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MAY 2016

Reader Harlalka reminds us that in some countries, 1,000 means "one."

One reader reports on remote control from the 1920s. And in a comment, a perspective that old sterotypes are fading.

COMMAS AS DECIMAL POINTS

To the Editor: I have two comments regarding the May 2016 issue. While I fully agree with M.N. Tarabishy ("No Free Lunch," Comment), I beg to disagree with his logic. The work of the compressor to put air into the containers is proportional only to pressure of water column and not "plus atmospheric pressure." Atmospheric pressure acts on compressor suction and therefore gets balanced out. Also, the total doesn't need to be multiplied by its natural logarithm to find out the work.

In one of the TechBuzz items ("Brazil Ports Move 1 Trillion Tons") the quantity of cargo is overstated by a factor of 1,000.

Akshay Harlalka, *Mumbai*

DRIVE BY WIRE IN 1921

To the Editor: Your interesting article about driverless vehicles ("Off to the Races," January 2016) states that "The dream of self-driving cars dates back at least to 1939, when General Motors showcased the idea ... ."

This technology has been regarded as imminent for longer than that. *Literary Digest* reported in March 21, 1921, about two radio inventors who had enabled wireless telephone and telegraph in a car (see photo at right). The article stated, "the young men have been testing out another invention, already in use in other cities, which controls the operation of any standard-make automobile by wireless."

Tim Athan, P.E., *Ann Arbor*

ENTROPY AND EVOLUTION

To the Editor: The word evolution has been used multiple times in recent issues of the *Mechanical Engineering* magazine.

Isn't evolution a full contradiction to the engineer's understanding of the Second Law of Thermodynamics? Every engineer who had to study thermodynamics, I'm sure, had nightmares of test problems while taking thermo. And,

COMMENT

THE FUTURE OF THE ENGINEERING WORKFORCE IS NOW

The inclusive vision of women in engineering is here today, and the prospects are brighter than they ever have been.

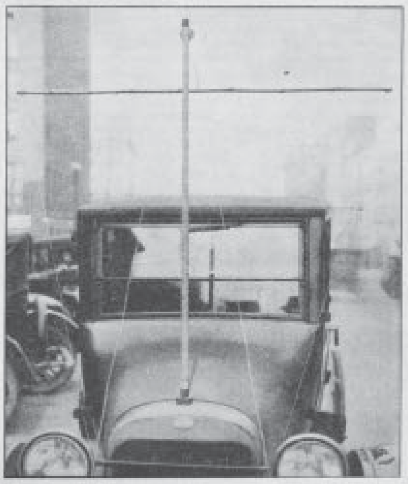
The conversation that is taking place over the April 2016 cover of *Mechanical Engineering* is just what the engineering profession needs. It can serve as a catalyst for change in our perspective on continuing transformations within the engineering community, help define the role of automation in the future of engineering, and most importantly continue the discussion regarding continued advancement of underrepresented groups in engineering.

As a past Senior Vice President and ASME Governor—and as a manager of engineers with a major global energy company—I have seen a remarkable advancement and acceptance in the diversity of today's engineering workforce. The change is sustainable and the talent and capability entering the engineering workforce by women and underrepresented minorities is truly remarkable.

The tide has turned and the future is now for these groups.

In my view the notion that the engineering profession will continue to be male dominated if action is not taken is passé and this view should not drive our thinking and actions as we move forward. The profession has used this phrase so much that it has become almost a conditioned reflex. In my recent business experience there has always been a very diverse group of qualified entry-level candidates competing for—and being selected for—growth positions. Management positions continue to be filled with females and other underrepresented groups and for good reason: They are highly qualified, creative, and provide value to their employers. The inclusive vision of the future for females is here now and the prospects are brighter than they ever have been.

In my interactions with students and early career engineers, I have found a universal concern over the role of the female engineer in the workplace. I believe this is driven from old stereotypes that we really need to expunge from our dialogue. With more conversation, time, and experience these concerns will be relegated to the



"DRIVE YOUR OWN WIRELESS!"
A motor-car carrying the wireless apparatus invented by Messrs. Cramer and Swain.

in my opinion, entropy was the worst.

So, where does evolution come in? According to *Merriam-Webster Dictionary*, evolution is "a process of continuous change from a lower, simpler, or worse to a higher, more complex, or better state." The Second Law of Thermodynamics states just the opposite in the *New American Webster Dictionary*: "Entropy is the ultimate result of the degradation of matter and energy in the universe."

In the future, *Mechanical Engineering* should edit out those ambiguous and incorrect uses of the known physical properties of our universe in its articles.

Dennis Hill, P.E., *Hudsonville, Mich.*

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.

distant past.

To me, the April cover of *Mechanical Engineering* with an abstract of a 1950's office environment serves to point out where we started and how far we have come, not where we are today. Nothing more needs to be read into this and divert the discussion.

The dialogue on the continued inclusion of diverse groups into the engineering profession and how best to attract more interest at an early stage in STEM programs remains relevant on a contemporary basis so that the current progress on the issue is not lost and the profession can continue to grow.

The ASME continues to lead the conversation on this issue.

RICHARD T. LAUDENAT, P.E., is an ASME Fellow who lives in East Haddam, Conn.

A STEALTH VIRTUAL CAR

ENGINEERING A STAND-IN TO PLAY NEW CARS ON TV

From movies to virtual ads in sports stadiums, realistic computer graphics have invaded our world. But to create a believable virtual car, one that makes you feel the acceleration as it comes out of a curve, you need to start with a real, physical car.

Not just any car, either, but the first car that morphs its size and performance to emulate anything from a Ferrari to a pickup truck.

That would be The Mill's fully adjustable Blackbird, named after the stealthy SR-71 spy plane. The automotive version is stealthy too, but in its own way. It is designed for what CGI artists call reskinning: placing virtual shapes and colors over a real car so it looks like another vehicle.

Surprisingly, the driving force behind the Blackbird is television ads, said Angus Kneale, chief creative officer of the New York office of The Mill, a British advertising agency, who has directed many commercials.

"When model years change, automakers might change only a few features," Kneale said. "Rather than refilming an ad, we digitally alter those features."

Creating a believable CGI of a moving car is not simple. It requires not only a physical car that moves realistically, which you can then reskin, but also complex photography to capture shadows and the reflections that would ordinarily

By adjusting its wheelbase, length, width, and suspension, the Blackbird can stand in for almost any car. Its performance is captured and a computer-generated vehicle body is then superimposed digitally.
Photos: The Mill

show up only on highly polished paint and chrome.

"I got to thinking, 'There must be an easier way to do this,'" Kneale said.

Kneale decided to design a single car that could emulate any vehicle on the road, which would simplify photography.

To build it, he turned to J.E.M. Effects, a special effects company that makes cars that withstand chases and crashes in films. They built a car that can extend its wheelbase and length by up to 4 feet and its width by 10 inches to mimic various makes and models, and can accept a wide range of wheel sizes. It has adjustable suspension and a powerful, electric motor that Kneale can program to match the acceleration, ride height, rigidity, and dampening performance of virtually any vehicle.

A car designed to emulate virtually any vehicle on the road.

To gather the photographs needed to create reflections, Kneale enlisted Lev Yevstratov of Performance Filmworks, which specializes in suppressing vibration in the long camera arms used to film Hollywood car chases. Yevstratov shrunk the large mechanical devices ordinarily needed to do that so that the four high-definition Blackbird cameras did not stick out from the vehicle's silhouette.

"The first time we tested it, it worked like a dream," Kneale said.

The Mill is already using the Blackbird to film virtual vehicles driving down roads of all sorts, and saving clients millions of dollars in CGI processing time, Kneale said. "If you want to film a campaign in Patagonia, it's remarkably cheaper to send one Blackbird than your entire line of vehicles." **ME**

ALAN S. BROWN

PORTABLE CERVICAL CANCER TREATMENT

In the developed world, regular screenings detect cervical cancer quickly, and doctors remove most lesions early enough to save lives. But in the developing world, the electricity needed to power therapeutic devices is unreliable, and the disease still kills nearly 300,000 women per year.

"It was alarming to see how devastating this condition can be," said Brian Charlesworth, an industrial and visual designer at the University of Utah.

In response, he and colleagues recently developed a portable battery-powered device that uses heat to destroy precancerous lesions in the cervix, while leaving surrounding tissue unscathed. They also launched a company called Cinluma to manufacture it.

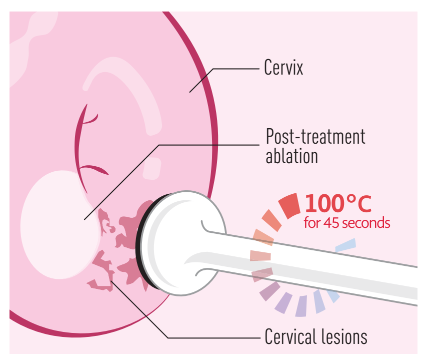
The World Health Organization has snapped up the device as a lead technology for treating cervical cancer in the developing world; the National Cancer Institute has awarded them a $2.4 million grant to do a four-year clinical trial in Zambia, and in June the U.S. Food and Drug Administration approved the device, also called Cinluma, to sell in the United States.

Cervical cancer lurks in a dormant state for 10-20 years. Doctors in developed countries typically stop it early using one of two methods: cryotherapy, which involves freezing the precancerous cells, and Loop Electrosurgical Excision Procedure, or LEEP, which involves using a small, electrified loop to excise the precancerous tissue.

Cinluma, which looks a bit like an electric toothbrush, instead uses a heating element that takes just six seconds to heat its tip to 100 to 120 °C. Applying that to lesions removes them within 45 seconds—much faster than the 11 minutes it takes cryotherapy to kill cells.

The Utah team designed its device for safety. Cinluma is built with high-temperature polycarbonate plastic, which is FDA-approved for human mucosal tissue. It employs analog and digital circuits, as well as a watchdog timer, to keep the device from overheating and injuring tissue. And unlike LEEP, it penetrates only about 4-5 mm into cervical tissue, which allows the treated tissue to slough off naturally every few months.

To work well where electric service is spotty, Cinluma also uses an inexpensive



Cinluma transfers heat to precancerous cervical tissue, which then dies and sloughs off safely. *Source: Cinluma*

12-volt, lithium-ion rechargeable battery that is readily available and can perform 20 procedures from one charge.

The University of Utah team is conducting clinical trials at the university's hospitals and clinics, and late in 2016, WHO's International Agency for Research on Cancer will start a four-year trial in Zambia, screening around 34,000 individuals and treating about 4,400 of them.

"The most exciting part of this project is being able to help save a woman's life," Chatsworth said. **ME**

CATHERINE ARNOLD is a writer in New York City focusing on science, technology, and nature.

SOLAR PARKING

THIN FILM PHOTOVOLTAICS ARE BEING DEPLOYED ON CURVED FABRIC SURFACES.

Sun shades installed over a parking area in England have thin-film photovoltaic cells incorporated into their lightweight fabric elements. *Photo: Solar Cloth Company.*

You probably haven't parked under a heated tensile fabric structure—or even heard that phrase before—but you likely will in the not-too-distant future.

One company that incorporates flexible, thin-film photovoltaics into fabric is seeing its products increasingly mounted on structures that shade parking lots and other environments, while another company uses a similar material to create tents that can be deployed by humanitarian aid workers.

The demand for distributed solar power is driving these innovations.

A few years ago, for instance, business park owner Clearbell Capital LLP of London sought a way to turn the parking lots outside 15 of its properties into solar structures to complement the low-carbon footprint of the parks' office buildings. The company sought a flexible and attractive parking cover that would blend into industrial and natural settings, said Natasha Prior, business manager at the Solar Cloth Company of Cambridge, England.

Prior's company had a solution. Solar Cloth, which recently merged with Base Structures, a fabric manufacture in Bristol, England, makes flexible, solar modules bonded to lightweight fabric or plastic that can be rolled and fit onto curved and flexible structures. The modules are comprised of lightweight and flexible thin-film photovoltaic panels.

Solar Cloth calls its technology tensile photovoltaics. The cloth can take solar applications into areas where traditional silicon panels won't work or aren't practical, Prior added.

Solar Cloth founder Perry Carroll first began work on a sail that incorporates solar cells to power electrical devices on yachts. The principles behind the yacht sail and solar cloth are the same, Carroll said.

The company uses a photovoltaic material called copper indium gallium selenide (CIGS).

SOLAR CLOTH CAN TAKE SOLAR APPLICATIONS INTO AREAS WHERE TRADITIONAL SILICON PANELS WON'T WORK OR AREN'T PRACTICAL.

"This is very different from the silicon solar that people are used to seeing on roofs," Prior said. "The CIGS panels are lightweight and flexible, meaning that they can be installed on curved or non-load-bearing roofs where other solar would not be suitable."

CIGS thin-film solar cells are created by depositing one thin layer each of copper, indium, gallium, and selenide on glass or plastic backing, along with electrodes on the front and back to collect current. Because they strongly absorb sunlight, the solar cells can be made from a thinner film than other types of cells.

The panels absorb light for long periods, so they generate energy from dawn until dusk, and capture light on cloudy days. They also have a higher shading tolerance, meaning they can be installed in tricky locations that don't face south or are shaded by trees or surrounding buildings. This feature was important to

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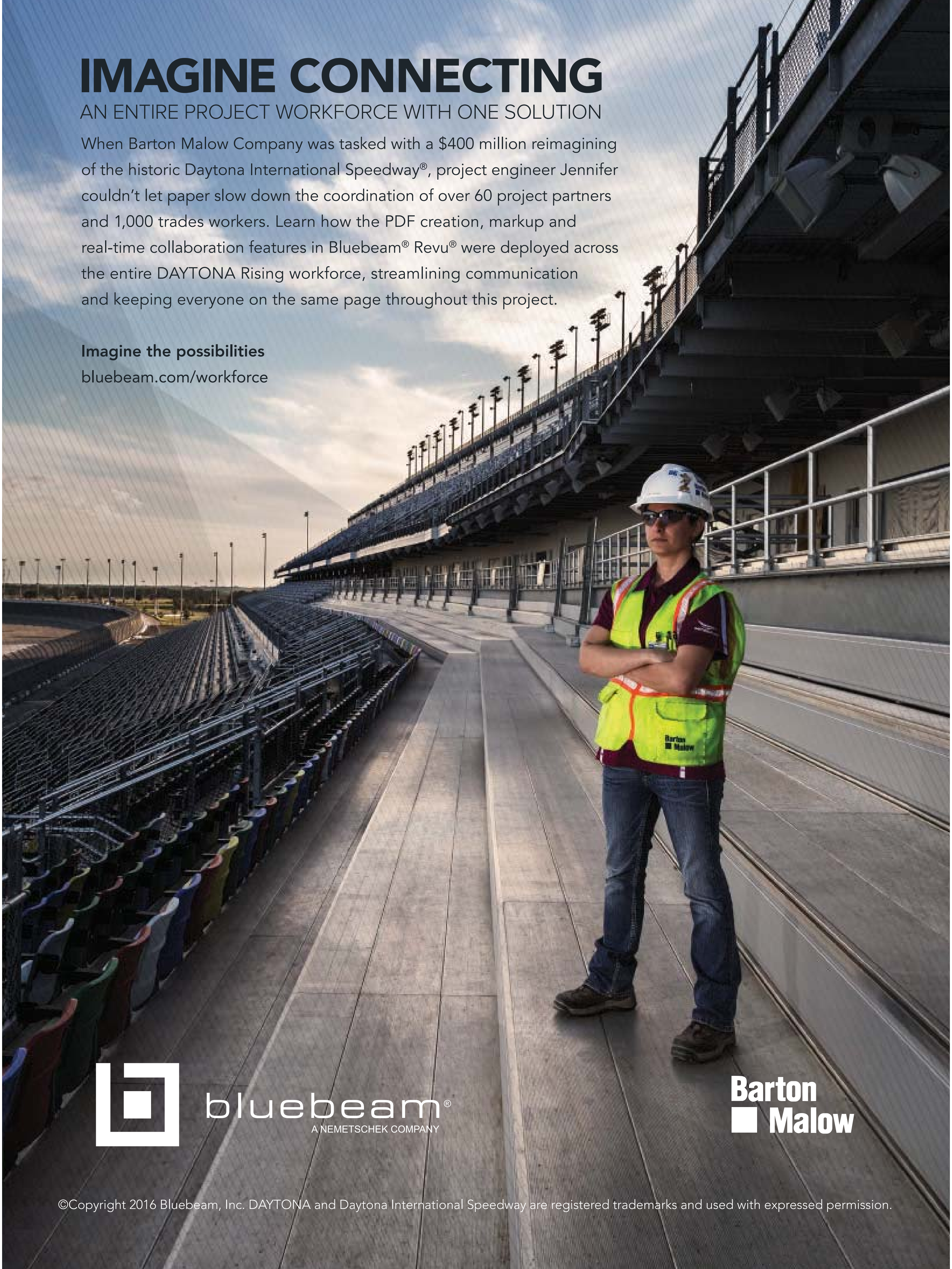
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HOW THE INTERNET OF THINGS IS IMPROVING LIVES IN DEVELOPING COUNTRIES

THE NEXT BIG THING IN INDUSTRY and home electronics may also have an enduring impact on development engineering.

Wirelessly connected sensors, actuators, and other hardware have already changed global development work—and signs point to bigger changes to come. A report by the International Telecommunication Union and Cisco Systems, called *Harnessing the Internet of Things for Global Development*, cites estimates that there may be 25 billion networked devices worldwide by 2020, or as many as 50 billion if you count RFID tags.

It's not a surprise that there will be a proliferation of sensors in the developing world, given that more people in those countries have access to 2G cellular network coverage than to basic services like electricity, sanitation, and clean water. What is surprising is the creative variety of applications that are already deployed.

Connected devices and big data analytics are monitoring farms, wildlife, air pollution, stove usage, movements of populations during disasters, epidemics, and even trends in people's moods through the words they use in tweets.

Houlin Zhao, secretary-general of ITU, wrote in the report's introduction that there are trade-offs implicit in the technology.

Increased monitoring could threaten privacy and safety, for example. Threats include "gaps between technical security and users' perceptions of security and trust, or the detailed information yielded by geolocalization technologies," Zhao wrote. "Moreover, the purpose for which technology and applications are developed does not always end up as the sole—or even major—purpose for which they are actually used."

With these cautions in mind, the technology is progressing in interesting ways. Here are some development engineering projects that take advantage of the Internet of Things today:

HEALTH: Los Angeles-based Nexleaf Analytics monitors the temperature of vaccines during transport to rural clinics in India. A thermometer device uploads data to the cloud in close to real time via a cell phone text- or data-messaging system. A server then sends updates and warnings when the temperature hits certain thresholds.

WATER: In Bangladesh, a team at the Robotic Embedded Systems Laboratory of the University of Southern California tested a network of 48 manual arsenic biosensors to monitor water quality.

In Kenya, a team from Oxford University affixed basic accelerometers (similar to those found in a mobile phone) to water-pump handles to monitor usage. A transmitter fits into the pump handle to deliver data via SMS.

Portland State University's SWEETLab has produced sensors used in a variety of projects, including water pumps in Kenya, cookstoves in India, latrines in Bangladesh, and water filters for hand-washing stations in Indonesia.

FARMING: The Syngenta Foundation of Basel, Switzerland, has deployed connected micro-weather stations through its Kilimo Salama ("safe farming" in Swahili) project. The stations monitor temperature and moisture in the air and soil, solar radiation, wind speed, and other factors, and transmit that information to insurance firms, which plug it into digital models that estimate losses after weather events. The insurance firms make mobile payments to the farmers based on the models, automating and speeding the claims process.

In India, 20,000 smallholder farmers use Nano Ganesh, a 2G-phone-operated unit that attaches to the pump of a drip irrigation system. An actuator operated by the phone turns the pump on and off. The farmer can see if the pump is getting electricity and if water is available.

DISASTER MONITORING: Following the 2004 Indian Ocean tsunami, the Indian Ocean Tsunami Warning System was created using kinetic sensors on the ocean floor. The sensors measure waves and water flow, and transmit warnings about potential tsunamis to disk buoys floating on the ocean surface. The buoys upload the information to government authorities via satellite.

Similarly, the Red Cross is experimenting with low-cost, solar-powered fire alarm systems in slums in Nairobi and Cape Town. The network sounds alarms and sends text messages to the residents and authorities, and uses GPS to locate the fire.

ENERGY: M-Kopa in Kenya built its business around networked devices. The company installs solar home systems at a discount and charges households for the amount of electricity that they use. The system cuts off the power if the meter runs out, and users can buy more with mobile payments. M-Kopa can remotely monitor the health of its systems and make repairs as needed. **ME**

ROB GOODIER is the editor of Engineeringforchange.com.

SEE FOOT. DON'T SHOOT FOOT.

Self-defeating behavior can **avoid a bruised ego**—but overcoming it is **far more rewarding**.

An amateur ski racer I knew was an excellent skier who could have placed high in most competitions. But he insisted on going all out in every race. Inevitably, he fell, sometimes spectacularly. In his mind, he would have won if he hadn't crashed, and others told him so. And he never skied hard only to finish out of the medals, either, which might have bruised his ego more than not finishing the race.

Self-handicapping, as this type of behavior is called, was explicitly identified in a landmark 1978 paper in the journal *Personality and Social Psychology Bulletin*. The authors, psychologists Steven Berglas of Harvard Medical School and Edward E. Jones of Princeton, wrote, "By finding or creating impediments that make good performance less likely, the [self-handicapping] strategist nicely protects his sense of self-competence."

Numerous scientific studies have confirmed the principle and parsed out the nuances of self-handicapping. People self-handicap in two ways.

Some actively hinder themselves with alcohol or drugs, or by curtailing effort or practice. A college student taking a test with a hangover after partying the night before has a self-serving narrative at the ready: "I did poorly because I was tired and didn't feel well, not because I'm stupid." And if he or she shines, all the better: "I must be really smart because I aced the test even with a hangover."

Others use excuses to justify a substandard performance, often beforehand. So another college student might pretend to have a hangover or a lack of sleep to excuse a disappointing grade.

Even the highly successful can fall prey. When Alexandre Deschapelles, a renowned 19th-century French chess master, noticed his skill waning with age, he insisted on surrendering a pawn and the first move to every opponent. This avoided any blow to his ego if he lost, and boosted them if he won.

An amateur ski race or a chess exhibition aren't of any serious consequence; they aren't the Olympics or a World Championship. But self-handicapping can impair one's job performance and, hence, one's career.

In the workplace, common tactics of self-handicappers are procrastinating, curbing or avoiding effort, and preparing inadequately. Some assign themselves unchallenging goals that anyone could achieve; others seek impossible workloads that nobody could complete. Self-handicappers who make excuses will plead: "I'm not very good at that," or "I didn't have enough time to do it right."

I once worked with a colleague who asserted, despite having achieved a doctorate in the life sciences, that a medical procedure we were developing was too complicated for her to understand. It was complicated, but for whatever reason, she didn't seem to want to try, so she adopted a self-handicapper's excuse.

Such self-handicappers delude only themselves since their colleagues swiftly see through the ploy. Thus, not only do they underperform, but others also regard them as underachievers.

What underlying fear leads people to such self-defeating behavior? "Their motive is the lack of certainty in their own competency and their ability to succeed," said Bobby Hoffman, a University of Central Florida professor of psychology and author of the book *Motivation for Learning and Performance*.

Awareness is the first step toward a remedy, said Hoffman, who is also an organizational improvement consultant. Although easy to see in others, admitting it to oneself is hard; the usual reaction is defensive denial.

The next step is to question the validity of self-handicapping, or as Hoffman put it, "create some doubt, some cognitive conflict, in the person who is using the strategy," including oneself. Self-handicappers can then adopt alternatives, like setting realistic goals or applying determined effort, which produce more satisfying outcomes.

Finally, Hoffman advocates for obtaining—or providing—guidance and feedback for this behavior, which can come from a supervisor, coworker, or even a spouse.

Taking these steps might feel like a stretch for a habitual self-handicapper. But it's good to remember that doing one's best is more rewarding in the long run. **ME**

JAMES G. SKAKOON is a retired mechanical design engineer and a frequent contributor.

“NIGERIA DOES HAVE OTHER energy resources but we’re talking about a balanced and diversified energy basket, and nuclear energy happens to be one that is considered.”

— Franklin Erepamo Osaisai, Chairman and CEO of the Nigeria Atomic Energy Commission, on the plans for Russia to design, construct, and operate a research reactor complex in Nigeria.

continued from page 12 »

SOLAR: FABRIC PANELS

Clearbell Capital, as many of its lots are partially shaded, Prior said.

The number of flexible solar modules bonded within one square foot of the solar cloth depends on the design and the size of the installation, Prior said.

Solar Cloth is not alone in manufacturing flexible, solar fabrics.

PowerFilm Inc. of Ames, Iowa, uses a similar fabric to manufacture a tent called the PowerShade that can generate 1 kW of power. This can keep the tent's occupants warm. It can also provide electricity for emergency equipment at short notice in remote places during humanitarian or natural disasters, said Brad Scandrett, PowerFilm's vice president of engineering.

A stumbling block to solar panel adoption is that they can be difficult to install and integrate with existing architecture and aesthetics, Prior said.

“Flexible solar cloth overcomes all of these problems and can add real value to existing and upcoming sites,” she added.

A ten-square-meter solar cloth weighs around 7.3 pounds. A conventional solar panel that covers the same space would weigh at least five times more, or between 35 and 48 pounds, Prior said.

That weight differential was critical for Clearbell Capital, which implemented the tensile technology because it was lighter and less expensive than traditional solar cell technology.

The solar cloth does come with tradeoffs. While the thin-film photovoltaics weigh much less than conventional solar panels, they produce 15 percent less power, Prior said.

Prior anticipates a range of colorful solar cloth following the merger with Base Structures.

“It’s getting to be like you don’t even know you’re looking at a solar installation,” she said. **ME**

JEAN THILMANY is an technology writer based in St. Paul, Minn.

Q&A CHARLES HULL

"I LOOK AT THEM ALL as my children and it's hard to pick a favorite," said Charles "Chuck" Hull about the current applications of 3-D printing. When you have invented a technology and seen it grow to adulthood, it's natural to feel that way. A private pilot and avid photographer, Hull has been inducted into the National Inventors Hall of Fame. He founded 3D Systems in 1986, initiating the 3-D printing industry—a juggernaut that is reinventing American manufacturing today.

ME: What led you to invent stereolithography?

C.H: The time between when you had the design [of a plastic component] finished and you saw your first finished part was typically six weeks, and then if you found problems with it, you had to recycle. When I saw these UV-curable coatings, I thought, Was there any way I could do some kind of imaging and manipulation to make prototypes of plastic parts? That's how I got the idea of stereolithography in the first place.

ME: When did you first envision 3-D printing being used in manufacturing?

C.H: We had our first product to sell commercially in 1988. That was the first 3-D printer, the SLA-1. We envisioned it for prototyping applications, but right away our customers started mentioning the potential for manufacturing applications. One of our first additive manufacturing applications was casting patterns. This was all very short-run manufacturing at that time.

ME: What pushed the technology into full commercial use?

C.H: The U.S. and, to some extent, the E.U. automotive industry were falling behind Asian manufacturers in terms of how quickly they could produce new cars. They were looking for ideas and technology to help speed up the design process. 3-D printing became a big part of that along with 3-D CAD, which was just emerging at that time. These companies, along with aerospace companies, helped push it forward to commercial use.

ME: There are currently several new technologies and 3-D printers promising speeds of printing unheard of before. What's your opinion on that?

C.H: I am a big promoter of that. We recently demonstrated a high-speed system that is a cell of three 3-D printers. It has robotic arms to pull out the parts, place them on finishing stations, and present them for the next step in an industrial production line. We [plan to] produce these small, high-speed 3-D printers and help companies integrate them into production lines. This kind of technology is going to be very important in taking additive manufacturing to production.

ME: The last five years have witnessed a 3-D printing boom, but will it continue in the next decade?

C.H: Absolutely. There was certainly a kind of hype, where people were expecting 3-D printing to instantly do everything. That hype, I think, has subsided. The good thing is that not just industrial people, but the population as a whole, understands what 3-D printing is. It is definitely on a growth curve and it has spread to all the corners of the world. That will continue.

ME: As an engineer, what is the most important lesson you've learned since the day you invented 3-D printing?

C.H: I was an engineer as I was developing this technology, and I was also studying and learning entrepreneurship. Probably the biggest lesson for me was learning how to grow a startup business. I had to learn more about the business side in order to make 3-D printing happen.

ME: What's your advice to young engineers who hope to invent a disruptive technology?

C.H: One key is being the very best engineer that you can be. For example, if you are a mechanical engineer—or whatever your engineering field is—understand that discipline in great depth and be an expert. The other is to do a lot of interfacing with other engineering technologies and with other professions. When the knowledge you have intersects with the issues and problems that you encounter in the broader society, disruptive inventions happen. You need both these elements to be a good engineer. **ME**

CHITRA SETHI is the managing editor of ASME.org. Her podcast with Hull has more on how he conceived 3-D printing: http://bit.ly/1Ooddip.

$140M FOR DATA-DRIVEN MANUFACTURING HUB

A new smart manufacturing research institute aims to push data-driven manufacturing forward by catalyzing advances in smart sensors, data analytics, and digital process controls. The Los Angeles-based institute will receive $70 million in funding from the U.S. Department of Energy over five years, and $70 million in matching funds from a 200-member consortium from academia, industry, and nonprofits. Manufacturing currently consumes one-third of the energy used nationwide, so making manufacturing more efficient would also reduce the nation's energy use.

The Smart Manufacturing Innovation Institute (SMII) seeks to transform manufacturing the way IT has transformed banking, health care, transportation, entertainment, and other industries, said Jim Davis, the new institute's interim executive director and CTO. SMII plans to provide data structures, connectors, and standards that will give companies an ability to readily assemble products from multiple vendors into a seamless system, he added. "We like to call it integration as a service," said Davis, who is also the Vice Provost of Information Technology at the University of California, Los Angeles.

SMII, which will launch late in 2016, will be the ninth of 15 planned manufacturing hubs in the Obama Administration's National Network for Manufacturing Innovation. Others focus on additive manufacturing, photonics, next-generation textiles, and flexible hybrid electronics.

"We're building what the manufacturing industry wants that no one company can provide," Davis said. ME

BIG NUMBER

524.4 Million

NUMBER OF BARRELS OF CRUDE OIL IN STOCK IN THE U.S., AT THE END OF JUNE 2016

PRODUCERS PUT MORE OIL ON THE MARKET this summer than consumers would buy. According to the Energy Information Administration, crude oil in inventory reached 524.4 million barrels, nearly 12 percent more than was on hand the year before. Consequently, U.S. gasoline prices during the summer driving season were lower than they had been in years.

Joints featuring aluminum, magnesium, and composites are tested for their ability to withstand design loads and forces.

FASTENING THE LIGHTWEIGHTS

GETTING IT TOGETHER IS ONE THING, but keeping it together can be an entirely different matter. This is especially true as automakers seek to meet higher fuel-economy standards. Many are turning to nontraditional materials, such as aluminum, advanced high-strength steels, and composites, which are not suitable for traditional welding and bolts. This month we look at two labs focused on developing alternative fastening solutions.

Sayed Nassar, a professor of mechanical engineering at Oakland University and an ASME Fellow, runs the Fastening and Joining Research Institute, a premier academic, nonprofit lab dedicated to fastening and joining materials. Originally founded in 2003 to improve the reliability of military vehicles, it now focuses on joining lightweight automotive materials.

"Joining two pieces of steel in a car body or bolting together cast iron components in the drivetrain are well understood," Nassar explained. "But when we substitute aluminum and composites, which have different properties, everything 'known' comes into question."

RE-ENGINEERING JOINTS

THE LAB Fastening and Joining Research Institute, Oakland University, Rochester, Mich.; Sayed Nassar, founding director.

OBJECTIVE Characterizing the physical properties of joints in dissimilar materials, including bolts and nuts, rivets, adhesives, and resistance welding.

DEVELOPMENT Thoroughly re-engineering joints modified by substituting metals, polymers, and composites for existing materials.

This is visible in the new Ford F-150 pickup truck. To fabricate its aluminum body, Ford could not use conventional spot welding, which works even with dirty or oily steel. Instead, it switched to adhesives and self-piercing rivets and screws, which provide a better grip on the soft metal.

Regardless of component, fastened parts must meet three bottom line criterion.

First, factories must be able to rivet, screw, or glue parts together at conventional vehicle-per-minute production rates. Second, they must withstand long-term operating conditions on the road—vibration, extreme heat and cold, humidity, corrosion, and shock—while protecting against collision. Third, the designs must follow best practices and eliminate errors to prevent the risk of litigation that could ultimately cost a firm hundreds of millions or even billions of dollars.

There is much more to such joints than just drilling holes, selecting the right screw thread or rivet, and specifying the right combination of bolts, washers, nuts, and torque values. Every joint is a system and must be engineered to work together as a system. In aluminum, for example, adhesives must keep parts from moving so screws cannot pull free of the soft metal. Nassar assesses each system based on FAJRI's six steps to fastener selection and joint design.

The first step covers the selection of bolts and nuts, screws, gaskets, washers, rivets, welds, or adhesives. The next looks at joint design, each specific to its application. The next two involve the choice and correct use of fastening tools: bolt and nut drivers, riveters, spot- or arc-welding systems, and adhesive dispensers.

"Fifth is determining what happens under service loads such as cyclic heated pressure, shock, vibration, and corrosion. It is done with computer simulations and physical testing," Nassar said.

Sixth is the joint's overall performance when exposed to harsh environments. These range from water and marine salt air to chemicals in pressure vessels and even radiation in nuclear

An LPW aftermarket aluminum differential cover installed on a Dodge Ram. Aluminum slashes weight, but generates stress when paired with iron.

McLaren Engineering designs and tests vehicle drivetrains and builds prototypes for original equipment managers around the world. For automakers seeking to add more lightweight aluminum to their product mix, Antoine Abboud is the go-to senior product engineer for designing the fasteners for die-cast housings and covers for drivetrain power transfer and rear differential units.

The power transfer system delivers power to all four wheels in vehicles with transverse mounted engines, while the rear differential allows a vehicle's two rear wheels to rotate at different speeds. Automakers want to shave weight with aluminum housings. Yet the guts of these power transfer systems need iron to survive heavy loads and high temperatures. That can lead to problems.

"The different rates of thermal expansion in iron and aluminum causes the bolt tension to increase at high temperature," Abboud explained. This is because aluminum expands at twice the rate of cast iron as it heats up, creating large stresses where the two metals are joined.

Abboud's rule of thumb to solve expansion mismatches is to use bolts with larger threads—twice the diameter of the bolt—to improve their grip. He also adds adhesives to lock the bolts into place.

Models are essential to simulate joint strength and possible failure modes, especially when using adhesives. "We also run physical tests on everything from torque to failure during heat cycling using ultrasonic methods," said Abboud, who outsources the work to a specialist firm.

Why all the fuss? As a rule, a 10 percent reduction in vehicle weight yields a 4 percent improvement in fuel economy, according to the Aluminum Association. But for McLaren, more than weight reduction is involved.

It also simplifies some processes. Because the metal is so soft, "there's no need to drill and thread the hole in advance, as must be done with iron. In production, eliminating this step is a cost saving," Abboud said. **ME**

REPLACING CAST IRON

THE LAB McLaren Engineering, a unit of Linamar Corp., Livonia, Mich.; Antoine Abboud, senior product engineer – fasteners.

OBJECTIVE Joining dissimilar metals in powertrain to yield savings in more than just weight.

DEVELOPMENT Replacing cast-iron housings and casings with die-castings in vehicle power transfer and rear differential units.

JACK THORNTON is a technology writer based in Santa Fe, N.M.

DOES COMPETITION DRIVE INNOVATION?

WHAT BECAME OF THE STANLEY STEAMER, the manual typewriter, or the black-and-white television? With our endless focus on the shiny and new, it's easy to forget that no technology lasts forever. Examining the birth and death of old technologies, though, can yield new insights into the nature of innovation.

A 1935 Studebaker Commander Land Cruiser at the Studebaker National Museum in South Bend, Ind. *Photo: Michael Barera*

Take the automobile, for example. Erik Gjesfjeld, a postdoctoral fellow at the Institute for Society and Genetics at the University of California, Los Angeles, recently adapted an approach used to study the evolution of fossil plant and animal species to examine the birth and death of 3,575 car models.

The research revealed why innovation has ebbed and flowed in the American auto industry since 1896. It also created a valuable quantitative tool to study the evolution of any technology, from typewriters to televisions.

Gjesfjeld earned a doctorate in archaeology studying the development of ancient Siberian pottery. "As archaeologists, we were aware that a lot of technologies go extinct over time, and we don't see that technology anymore," he said.

Thanks to carmakers' habit of giving models unique names and dates (a 1965 Mustang, a 2005 Prius), Gjesfjeld and his post-doctoral advisor, UCLA evolutionary biologist Michael Alfaro, had a ready trove of data on the birth and death of car models.

Using a statistical method called Bayesian modeling, they examined 3,500 models produced from 1896 to 2014 to determine which of three factors determined innovation the most: economic growth, changing oil prices, or the diversity of car models already on the market.

They found that since the 1980s, fewer new American car models have been introduced each year, and fewer have been discontinued. And to their surprise, they found that more have gone extinct than have been introduced. "We may be driving more cars, but we're driving more of the same cars," Gjesfeld said.

The results square with theories of technological evolution that predict that as technologies become ever more specialized, it gets more expensive to make radical innovations, and diversity decreases, the researchers reported recently in the open-access journal *Palgrave Communications*.

The researchers' model predicts the ongoing explosion of electric car models, but it also predicts that competition in the marketplace will ultimately kill off many of them.

The results suggest that "later in the life of an industry, it's really hard to make new things," Gjesfeld said. ME

DAN FERBER

SHIPBUILDING BACKLOG AT 12-YEAR LOW

South Korean shipyards are starting to feel the effects of a global shipbuilding slump, with the backlog on orders lower than it has been in 12 years.

According to data compiled by the global research firm Clarkson Research Services, the shipbuilding order backlog held by Korean shipbuilders was 25.1 million compensated gross tons at the start of July. This is a 20 percent drop from the same point last year and reflects a rate of new orders that is less than the capacity for the companies to complete them.

Order backlogs held by Chinese and Japanese companies sank 11 percent and 14 percent, respectively, over the same period, Clarkson's data showed.

China, South Korea, and Japan are the three largest shipbuilding nations and together construct more than 90 percent of the commercial vessels produced each year.

The findings were reported by the *Korea Times* in July.

The decline in orders has hurt the South Korean shipbuilding sector's profitability, the newspaper reported. South Korea's top three shipyards suffered a combined operating loss of $7.4 billion in 2015, due to increased costs stemming from delays in the construction of offshore facilities and the industry-wide slump. ME

INDUSTRIAL-STRENGTH 3-D PRINTING

For more than two decades, engineers have been using 3-D printing to build prototypes, but most factories still rely on traditional manufacturing methods for mass production. Recently, however, Siemens and Hewlett Packard joined forces to marry Siemens's CAD/CAM and CAE software with HP's Jet Fusion 3-D printers. Their goal: to crank out production-quality parts at 10 times the speed and half the cost of other commercial 3-D printers.

"To integrate 3-D printing into an industrial environment, you have to manage the data," said Andreas Saar, vice president of manufacturing engineering solutions at Siemens PLM Software, a division of Siemens.

Most of today's high-end 3-D printers make plastic parts by depositing molten plastic through a print head one line at a time, or by fusing plastic powders in a pattern.

HP's Jet Fusion 3-D printers instead use print heads like those in ink jet printers, except they align five to ten of them to sweep across the build surface and in one pass deposit a layer of the growing object. In a perpendicular pass, other print heads then deposit fusing and detailing agents. Then a white-light lamp fuses the entire pattern into a solid layer.

Currently, the system only works with a single color of nylon (aramid) plastics. HP plans to introduce systems that can print but individual voxels (three-dimensional pixels) with different colors.

That capability would enable designers to build a visual wear indicator into parts, such as a rack and pinion in a car's steering system, a mountain railway, or a valve in a water pipeline. As thin layers of material wear away through repeated use, the color of the rack would change, making it easy to spot a worn part.

With further development, Saar said, the system could also vary the material's strength, density, texture, friction, and electrical and thermal characteristics voxel by voxel throughout a part.

By the end of the year, Siemens plans to introduce a "special [software] package for these materials, which is targeted and focused and has all-in-one functionality, so customers need very little effort to get this technology working," Saar said. ME

ROBOCARS WOULD SAVE HUMAN LIVES

THE FATAL COLLISION OF a 2015 Tesla Model S on autopilot with a tractor-trailer in Florida earlier this year threw a harsh light on autonomous vehicles.

Yet a new study shows that partially autonomous cars, which are not fully driverless, could potentially save thousands of lives and hundreds of billions of dollars.

"While there is much discussion about driverless vehicles, we have demonstrated that even with partial automation there are financial and safety benefits," said study author Chris T. Hendrickson, who heads the Traffic21 Institute at Carnegie-Mellon University in Pittsburgh.

Cars with autopilot systems like the Tesla are rare and costly. Many modestly priced cars, however, have added autonomous safety systems.

The study focuses on three: lane departure warning, which cautions drivers if they drift from their lane; blind spot monitoring, which warns of nearby cars drivers cannot see in the mirror; and forward collision warning, which sounds an alert (and may automatically brake) if a car gets too close to the vehicle in front of it.

Hendrickson's team analyzed police accident reports and fatal injury data. The researchers estimated that at least one of these three technologies could have affected 24 percent of the 5.3 million collisions reported to police in 2012.

If these technologies were 100 percent effective and deployed in every car on the road, they would prevent or reduce the impact of as many as 1.3 million accidents annually, including 133,000 injury crashes and 10,100 fatal crashes.

Based on this best-case scenario, Hendrickson calculated that partial autonomy would save the United States $202 billion in accident costs. This is equivalent to $861 per vehicle, even after taking into account the cost of the technology.

Those savings are based on the average cost of a crash, $162,400. This includes $47,021 in economic costs, such as medical care and auto repairs, and $115,414 in quality-adjusted life years, a measure that takes into account changes in health and lifespan due to an accident.

The researchers also calculated a lower boundary for savings. They based this on the observed decrease in collisions and accident severity in 2012. They found the three technologies would save $18 billion while costing $14 billion to install, a net annual benefit of $4 billion, or $20 per vehicle.

Hendrickson expects those benefits to rise significantly as crash avoidance technology improves and costs fall. The study "creates a framework for regulatory action encouraging early deployment of partial automation technologies," he said. **ME**

SMALL REACTORS + HELIUM TURBINES = NEAR-TERM ENERGY SAVINGS

LOOKING BACK

Engineers were beginning to consider concepts for the second generation of nuclear power stations when this article was published in September 1976.

BY CURT KELLER, RETIRED FROM ESCHER WYSS AG.

An ASME Fellow who had received the R. Tom Sawyer Award earlier in 1976 described the economic and efficiency advantages of combining small nuclear reactors and closed-cycle gas turbines.

The building costs of big plants are still high. Although the cost per kilowatt installed has diminished over the years, distribution costs have increased. Therefore, the customer does not actually profit much. A number of fossil-fired power/heat plants with closed-cycle gas turbines are in service in Germany with very good economic results. Some of them have operated over 100,000 hours. Especially notable is the power/heat plant in Oberhausen. Also, the first helium gas turbine has recently been put into operation in Oberhausen—the second power/heat plant in that city.

It is recommended that serious study be given to smaller nuclear power/heat plants with closed-cycle helium turbines in a direct cycle [100-300 MWe] to serve the aforementioned purposes. To our knowledge, a comprehensive detailed study of this approach has not been made. Consideration should be given to all factors, not only to the reactor and the turbomachinery, but also to such factors as siting, cooling, and necessary auxiliaries. Such a plant would be air-cooled; it could be built wherever it is needed, with a relatively free choice of site—being near a river is not imperative. Due to the small size, both with regard to the reactor and machinery, the system could also be located in a cavern. This improves safety and environmental protection factors always emphasized by reactor people.

A few other points should be mentioned. Automation and control are much simpler than with steam turbines. The number of auxiliaries is reduced considerably. No circulator is necessary for the cooling and heat transfer from the reactor to a secondary loop. The load regulation is by pressure level change both in the machine and in the reactor—at constant temperature and constant efficiency. This offers the possibility of adapting such a plant to varying load demands and it is not restricted to constant base loads only, as are today's big nuclear plants. The closed-cycle system has the unique characteristics of constant efficiency over a very broad power range and independence of power and heat production.

Instead of building only gigantic nuclear power plants, systems with power plus heat production should also be developed. There is a widespread need for them. High-temperature reactors with closed-cycle helium turbines in a direct cycle can lead to cost savings and much better utilization of fuel by purposeful use of waste heat from medium-sized plants.

FORT SAINT VRAIN

Within months of Curt Keller laying out his concept for a nuclear-powered gas turbine plant, an innovative nuclear generating station was producing electricity. The Fort Saint Vrain Generating Station near Platteville, Colo., was a high-temperature helium-cooled reactor intended to be more efficient and less costly than the light-water reactors that had been built to date. The circulating helium only cooled the fuel; steam generators in the reactor vessel carried the heat to steam turbines to generate electricity. The innovative design was more challenging to perfect than expected. After an official start of commercial operations in 1979, the 330 MWe reactor was shut down for good after only 10 years. The old nuclear power plant site now hosts six natural gas combustion turbines with a nameplate capacity of 969 MW.

Fort Saint Vrain Generating Station
Credit: U.S. Dept. of Energy

Application of the extensive experience with many fossil-fired, closed-cycle plants in Europe with many hundreds of thousands of hours of operation and a number of special closed-cycle applications in the U.S. does not require long-term development. It would, therefore, be wise to start with well-known components to demonstrate in the near future the many potential advantages of a second generation of nuclear power plants. ME

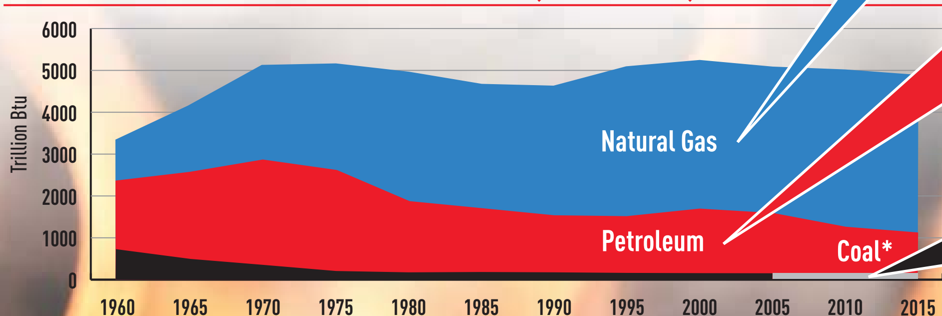
BY THE NUMBERS: KEEPING THE HOME FIRES BURNING

For all the interest in renewable energy, fossil fuels still supply around 80 percent of the energy consumed in the United States. Policymakers who want to bring that number down generally look at the power industry or transportation. But households burn a lot of fuel, too.

According to the Department of Energy, U.S. households consumed 20.9 quadrillion Btus of energy in 2015, out of the national total of 97.7 quads. A lot of that consumption is electricity, both 4.8 quads of direct electricity use and 9.5 quads of what the DOE calls "electrical system energy losses": the energy content of fuel that isn't converted to electricity and the energy lost in the transmission and distribution network.

But most of the direct energy consumption in households comes from burning fossil fuels, for both home heating and cooking. According

RESIDENTIAL SECTOR ENERGY CONSUMPTION (FOSSIL FUEL)



** Data not available after 2005*

to the 2013 *American Housing Survey*, the most recent edition the U.S. Census Bureau has published, only 28 percent of the 116 million occupied housing units were "all electric." Natural gas was used in 69 percent, while about 7 percent used fuel oil. (A little less than 2 percent burned wood.)

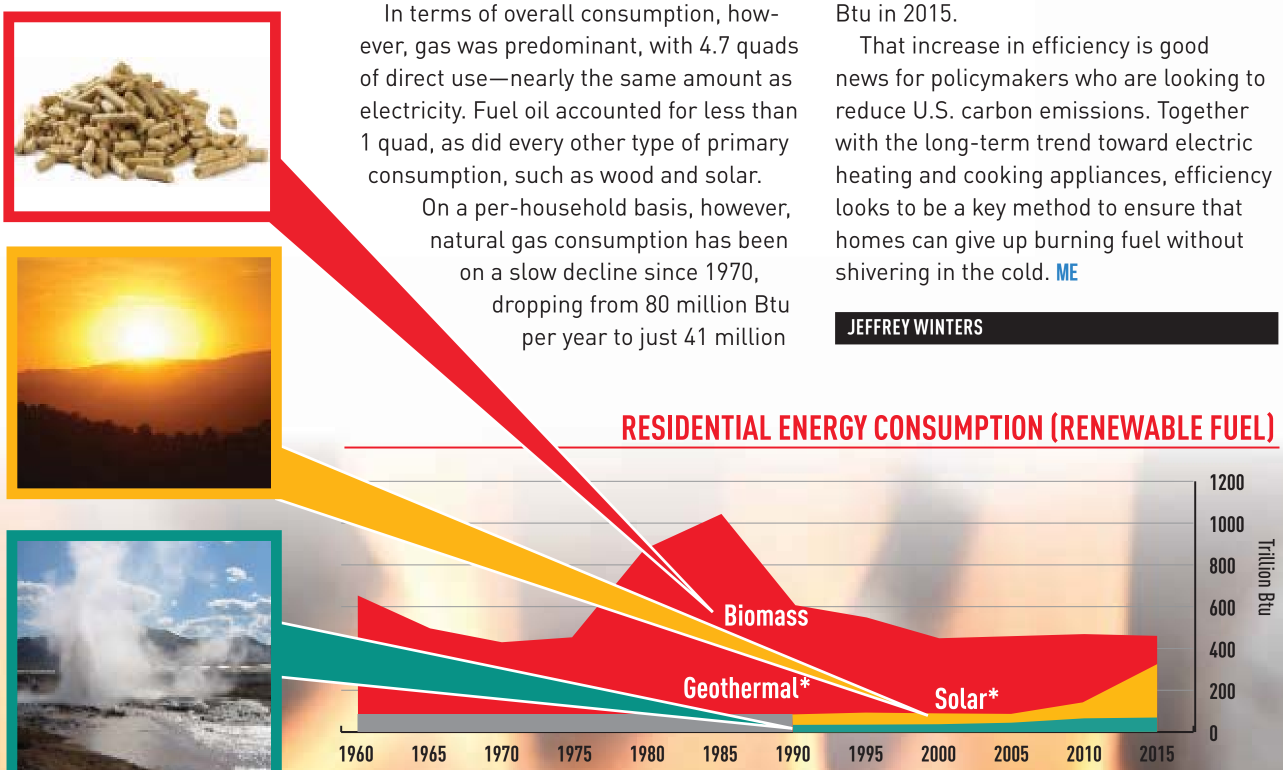
In terms of overall consumption, however, gas was predominant, with 4.7 quads of direct use—nearly the same amount as electricity. Fuel oil accounted for less than 1 quad, as did every other type of primary consumption, such as wood and solar.

On a per-household basis, however, natural gas consumption has been on a slow decline since 1970, dropping from 80 million Btu per year to just 41 million Btu in 2015. Some of that difference has been made up by electricity—the number of electric-heated households has shot up by a factor of eight since 1970—but efficiency has played a big part. Average household energy consumption, not counting system losses, has declined from 158 million Btu in 1970 to just 97 million Btu in 2015.

That increase in efficiency is good news for policymakers who are looking to reduce U.S. carbon emissions. Together with the long-term trend toward electric heating and cooking appliances, efficiency looks to be a key method to ensure that homes can give up burning fuel without shivering in the cold. ME

JEFFREY WINTERS

RESIDENTIAL ENERGY CONSUMPTION (RENEWABLE FUEL)



* Data not available prior to1990

F34

MANUFACTURING GETS SMART

INFORMATION TECHNOLOGY ON THE FACTORY FLOOR PROMISES A REVOLUTION IN PRODUCTIVITY. BUT CAN MACHINES, PRODUCTS, AND PEOPLE *REALLY LEARN TO TALK WITH EACH OTHER?*

BY ALAN S. BROWN

The industrial hype machine has not worked this hard since the early days of the Internet.

The object of its affections is the full-on mashup of manufacturing with modern information technologies. This goes by many names, from Industrie 4.0 and digital manufacturing to cyberphysical systems and smart—no, make that brilliant—factories.

What they all have in common is the use of intelligent software and machines to interact with one another (and with people) autonomously, both in the factory and through the cloud. According to boosters, this new combination of brains and muscle will revolutionize manufacturing in ways that rival the introduction of steam, electricity, and automation.

Beyond the hype, this could lead to some real and startling changes.

In the data-driven factory of the future, engineers would receive instantaneous feedback on the cost of design changes and on which parts are most likely to fail in the field, so they can improve designs and change production processes.

Factory machines and logistics equipment would communicate with one another autonomously to assign and route jobs through the factory—and reroute them when unexpected problems arise. Cloud-based AI would constantly compare parts and processes to optimize performance.

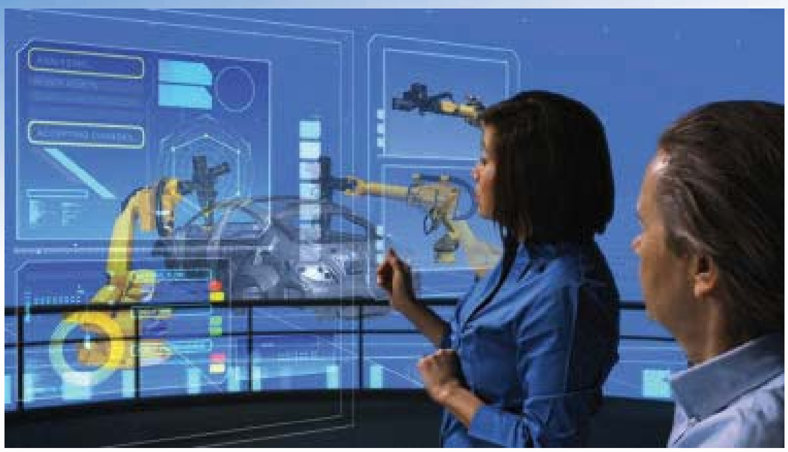
Perhaps one day, entrepreneurs and engineers may even create entire virtual factories, buying time on underutilized assets the way they buy products from different vendors on Amazon.

This vision, like that of the early Internet pioneers, is compelling—and perhaps even closer than we think.

TOWARD DIGITAL TWINS

The Internet blossomed because desktop computers and corporate networks were ready to plug in. Similarly, data-driven manufacturing is emerging now because many critical technologies—from networked machines to the alphabet soup of manufacturing software—PLM, ERP, CAD/CAM, CFD, MES, DMS, PLC and more—are already in place.

Today, these discrete systems collect some of the data, some of the time. Data flows freely within a single software program, and more or less well within software suites from a single vendor. Problems arise when they have to make sense of



Simulation models will play an important role in running factories more autonomously.

machines in geographically diverse factories that may use software from multiple vendors.

Consider engineering design software. While most computer-aided design programs have proprietary file formats, and readily share information with CAD systems from different vendors. They also export data to simulation software and computer-aided manufacturing systems.

Unfortunately, sharing data is far from seamless. When sharing files between CAD systems from different vendors, engineers must still review drawings to fix missing, misplaced, or disconnected features. Some CAD systems share only some of their data. For example, they might keep the material specifications essential for efficient machining locked away. Nor can engineers see how a design change affects a part's performance or its machining time without running separate software programs.

All this makes CAD data sharing too complicated for the plug-and-play world of data-driven manufacturing, said Stephan Biller, GE Global Research's chief manufacturing scientist, who leads the company's digital manufacturing charge under the "Brilliant Factory" banner.

"We want to be able to change a product in CAD and have those changes propagate automatically to product and factory simulations. That way, we get immediate feedback on how design changes modify cost, time, and materials," Biller said.

Biller also wants to link factory software with downstream supply chains and upstream customer service data. This is especially important for GE, which guarantees the performance of turbines and many other products it sells and services.

"When we open a jet engine, we can see exactly how its parts behaved. Maybe some parts are over-engineered or wearing too fast. I want to train technicians to get that information into a digital twin, a model that is an exact virtual twin of that product."

By constantly updating that information, GE wants to use the digital twin to help improve future designs and predict when to take in products for service. "We can see who made the parts, see how operating conditions affected performance, and improve production. The same data can help us manage demand for our service shops better, too," Biller said.

Much of this data already exists in manufacturing execution systems, product lifecycle management software, and enterprise resource planning systems. The problem, Biller explained, is that these systems are typically not well integrated. His goal is to tie that information together. That way, he can capture field service feedback and other types of information that's rarely shared among designers, manufacturers, and technicians.

This is an ambitious agenda. So ambitious that Biller's boss asked him, "How do you know when you're done?"

Biller's answer: "I'm done when I can launch a virtual product in a virtual model of my plant, then run it in my plant and the product behaves exactly like the simulations predicted."

INTERNET OF THINGS

As software gets better at communicating, ubiquitous sensors are adding more data to the mix. A lot more. The industrial Internet of Things is powered by cheap sensors and controllers, some with distributed intelligence, that engineers can slap onto everything from milling centers to RFID readers that track work in progress.

Many companies, such as ABB, Emerson, GE, Honeywell, Mitsubishi, Siemens, and many others, already sell systems that do this. Their platforms are proprietary and costly.

Less expensive IoT sensors and controllers threaten to disrupt this status quo with the same strategies that have slashed prices and boosted the performance of consumer electronics for decades: simple construction, open standards, plug-and-play installation, ease of use, and the substitution of wireless data transfer for expensive cabling.

At Siemens PLM Software, Alastair Orchard, who leads the company's digital enterprise project, is not trying to fight the rising tide.

"We have to embrace the Internet of Things," he said. "We can't try to defend the shop floor and force our customers to take the most expensive and awkward way of doing things. We want to preserve IoT's ability to quickly, simply and cheaply get data."

Fortunately, years of mergers, acquisitions, and globalization have taught companies like Siemens how to weave software and hardware from different vendors into a single system.

But are they prepared for the sudden proliferation of cheap sensors that IoT is making possible? These devices will generate tsunamis of data, enabling machines to talk more fluently with one another while machine-learning algorithms probe the information for better ways to run the plant. But integrating data streams creates its own challenges, said Lihui Wang, an ASME Fellow and well-known expert on digital manufacturing who chairs sustainable engineering at Sweden's Royal Institute of Technology.

"I don't think many people realize the complexity of combining different types of data," Wang said. "Even if we are talking only about digits, we have to deal with the high volume, velocity, and variety of measurements. And some data is unstructured, like speech, photographs, and drawings, which are more difficult to analyze."

To transfer data among various devices, German motor drive and control giant Bosch Rexroth tries to use open standards, said Thomas Buerger, the company's vice president of engineering automation systems. Unfortunately, while some open standards exist, others are still works in progress.

Nevertheless, Buerger argues that installing and integrating extra sensors is worth the fuss. He points to a cardboard carton-folding machine that links a Bosch Rexroth controller with a humidity sensor. It automatically compensates for changes in cardboard stiffness, which varies depending on whether the air is dry or soggy.

As the IoT takes hold, factory machines will work together to keep products flowing, and adapt autonomously to their environment. They will also learn from similar machines in other factories around the world—but only if they can rely on the cloud.

INTO THE CLOUD

Not long after the Soviet Union collapsed, German manufacturers sensed an opportunity. To take advantage of lower labor costs, they began to build factories in Eastern European countries. Those firms had always trusted an intensely loyal workforce to guard their designs and trade secrets closely within their factories. They were unsure what might happen beyond their borders.

To maintain tight control over this information, they began storing it in centralized corporate data centers. They gave local engineers access to only

> "I'm done when I can launch a virtual product in a virtual model of my plant, then run it in my plant and the product behaves exactly like the simulations predicted."
>
> — Stephan Biller, Chief Manufacturing Scientist, GE Global Research

the documents they needed, and barred them from roaming to other parts of the digital library.

Today, data-driven manufacturers still want to hold intellectual property close, but they also want to use centralized data centers to help manage shop floor production. In other words, they want to use cloud computing to help run smart factories.

There are good reasons to do it. Centralized, cloud-based software is always up-to-date. It includes the latest security enhancements, and it runs on the latest IT equipment.

What's more, large data centers are highly ef-

ficient, low-cost providers. They could support data-driven production without the company incurring the cost of running a large data center, said Ihab Ragai, who worked 20 years in manufacturing before becoming an assistant professor of engineering at Penn State Behrend in Erie, Pa.

Another plus is that companies can aggregate data on similar equipment in multiple factories. They could then use analytics to benchmark or discover patterns that might affect output. Such analysis could extend to performance in the field.

"If they do this, they will have a database that helps them predict part lifespan and how that lifespan changes if they run their equipment faster or under more extreme conditions," Ragai said.

Yet factories cannot yet rely entirely upon the cloud. Ragai recalls visiting an Egyptian die casting plant when an undersea Internet cable broke. It took three days to restore the Internet connection.

"Ten years ago, people were asking if online banking was risky. Now it's accepted. That same technology can be applied to cloud manufacturing to protect data privacy."

— Lihui Wang, ASME Fellow and Sustainable Engineering Chair, Sweden's Royal Institute of Technology.

"Now, imagine if that casting facility got all its drawings from the mother company," Ragai said. They would have experienced a costly shutdown unless they had satellite communications.

Still, as German firms are well aware, the cloud's most important stumbling block is security, said Wang, of Sweden's Royal Institute of Technology. If plant engineers don't feel confident in their cloud-based control software, then they might end up printing out diagrams or downloading backup files just in case. This poses the very security challenges that IT managers turn to data centers to avoid: stacks of valuable proprietary information airing on desks or sticking out of local jump drives.

Solutions are possible, Wang added. "Ten years ago, people were asking if online banking was risky. Now it's accepted. That same technology can be applied to cloud manufacturing to protect data privacy."

Nevertheless, he said, "Companies should also understand that there is no 100 percent security. They have to accept some risk. To reduce that risk, maintain your core software inside the plant."

FACTORIES FOR HIRE

Clearly, data-driven manufacturing is a work in progress. It is easy to see the barriers and perhaps miss the potential. That is why companies like Bosch Rexroth, GE, and Siemens have built plants to demonstrate how data can make a difference.

For example, in the medieval German town of Amberg, a Siemens plant fabricates programmable logic controllers (PLCs), which automate industrial machines and processes.

Amberg plant's performance is impressive. It can turn around a custom PLC for any of its 6,000 customers in just 24 hours. And of the 12 million PLCs that will roll off the plant's gleaming tile floors this year, only 121 (or 0.001 percent) are likely to have any defects.

The reason for this lies in how Siemens uses data and simulation models to run its plant.

Once a customer orders a PLC from Siemens, a computer system in the Amberg Electronics Plant assigns it a unique product code and creates a virtual model that defines the manual and automated processes needed to make the PLC. The system compares the order with other orders to see if it can group products with similar parts together for faster processing. It schedules time on machines that are free, and lines up automated carts to shuttle the components from one work center to another.

Machines assemble PLCs from capacitors, resistors, microchips, and connectors, inspecting components after each operation. As this is going on, the plant's operating system is comparing the time needed for each sequence of tasks with a simulation model of the plant, checking for any deviations that might signal a problem.

The entire conversation takes place between machines, with no human intervention. Only if there is a problem—a flaw needs repair, or a ma-

Siemens' Amberg plant uses data-driven manufacturing to produce 12 million controllers annually. Only 0.001 percent have any defects.

chine begins to deviate from its allowances—does the plant notify a human specialist.

"In Amberg, there are 50 million conversations each day between those agents and smart automation. They are saying: 'Set up correctly to do this. Who can do the next process? Are you ready? Logistics, route me over there. Check and double-check.' It's an almost continuous conversation, and it gives us our flexibility," Orchard said.

In the future, those data-driven conversations will make plants even more adaptive and autonomous. Just as apps and Internet connectivity spurred innovation in smartphones, data-driven factories are likely to evolve in new ways

For example, Dirk Schaefer, as associate professor of design engineering at University of Bath in the United Kingdom, sees a time when highly connected factories will one day be able to sell machine time as a service. Firms that need more output to meet demand or replace a broken piece of equipment could rent it.

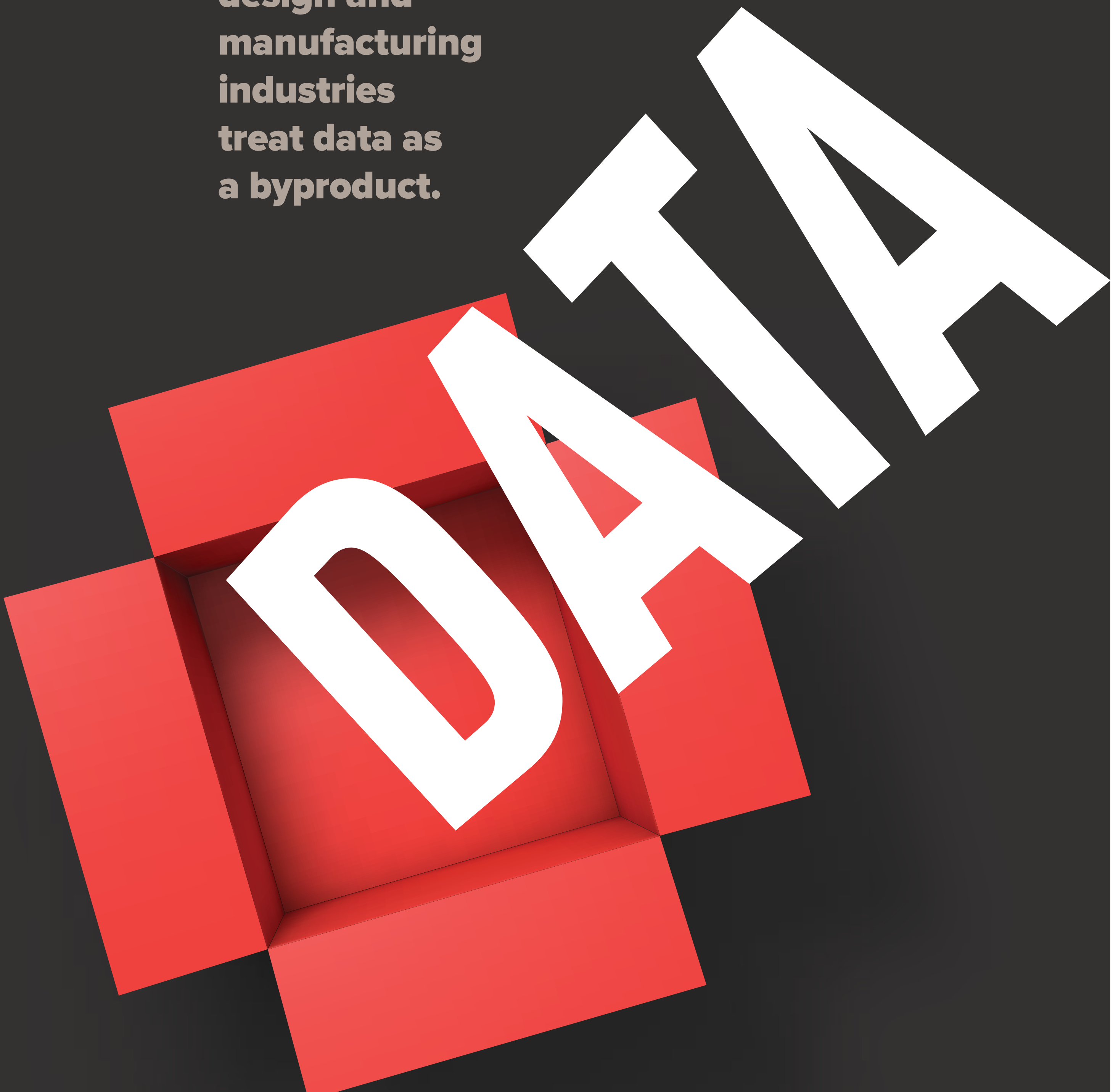
Eventually, a global manufacturing network would emerge, and businesses and even individuals could rent machine time online the same way we book cars or hotel rooms online today, Schaefer said. There would be no lasting contracts, supply chains, or physical footprint. "This would allow for entirely new ways of inventing and making breakthrough products," Schaefer said.

When Schaefer trotted out his cloud-based design and manufacturing paradigm at conferences five years ago, engineers were skeptical. Today, they are listening.

After all, we live in a world where a single factory supports 50 million digital conversations every day. Who knows where those dialogues could lead? **ME**

ALAN S. BROWN is associate editor at *Mechanical Engineering magazine.*

Today's design and manufacturing industries treat data as a byproduct.



Data comes out of storage.

AND MANUFACTURING INNOVATION

Many of today's designers and manufacturers view data that's generated during the development of a new product or manufacturing technique as a mere byproduct of those processes.

As a result, only the most rarified of the data produced during design and manufacturing processes is curated in digital formats that make it accessible and meaningful. Too often, we leave potentially valuable data in a state that realizes no current or future value. Enterprises of all sizes orphan important data on the shop floor.

This is a lost opportunity. A sufficiently rich data set that is fully accessible enables designers to discover previous processes and leads—including false starts and dead ends—that could develop into new solutions. Rather than throwing out this valuable data or leaving it in inaccessible forms, industry, researchers, and others may soon be able to use tools to explore this information and amplify their intelligence and experiences.

Before we can get to that point, though, we have to rethink the relationship between data and manufacturing innovation. We will have to understand that data is the central and most essential product of engineering design activity.

By William Regli

"DATA IS NOT A MERE PRODUCT OF PRODUCT LIFECYCLE ACTIVITIES—IT IS DATA THAT GIVES RISE TO THESE ACTIVITIES IN THE FIRST PLACE."

Keeping data isn't enough.

Data can be meticulously archived but also rendered utterly useless. For instance, it could be kept on paper or in an analog data format such as old Applicon files printed to aperture-style punch cards. Digital data stored in unsupported storage technology, such as tapes or floppies, is just as inaccessible. Digital data could be in a lossy or derivative format, such as a 3-D CAD drawing archived as a 2-D PDF, or it could lack the context or metadata to make it discoverable.

Another element usually missing from stored data is the thought process behind its creation. Design produces many branches that—as a collection—can be valuable; yet those design decisions, explorations, R&D tests, and alternative analyses are typically discarded.

While industry decision makers recognize that product and manufacturing data is important, they often lack an understanding of what constitutes product-related data and the actual value of that data.

For instance, industry today is rapidly adopting something called the

Industry today is rapidly adopting something called the DIGITAL THREAD, a best-practice in product data management that emphasizes a closed-loop process in which product lifecycle data is linked and traceable to design intent.

digital thread, a best-practice in product data management that emphasizes a closed-loop process in which product lifecycle data is linked and traceable to design intent. According to a definition published by the Defense Acquisition University at Fort Belvoir, Va., which provides acquisition, technology, and logistics training for military staff and contractors, the goal of the digital thread is to "inform decision makers throughout a system's lifecycle by providing the capability to access, integrate, and transform disparate data into actionable information."

The Digital Manufacturing and Design Information Institute (DMDII) has proposed that the digital thread serve as the backbone with which to aggregate and use manufacturing data. That would create a seamless flow of data across the product lifecycle and the information systems that manage and use this data. Some experts speculate that the thread will enable data analytics and reduce the time and cost to design and manufacture a physical product. Organizations such as the National Institute of Standards and Technology (NIST), GE, and many others have written about the promise of the thread to transform manufacturing into a fully digital enterprise.

In this way, the digital thread supports the requirements of the conventional manufacturing supply chain and the organizations that lead them. Yet in this Internet-of-things enabled supply chain, the data of interest is often limited to the very narrow digital thread that ties together the product data, production data and lifecycle information for a finished artifact.

These best practices in design and manufacturing stand in stark contrast to data revolutions being fomented in other fields. Beginning in the late 1990s, for instance, several large research initiatives have transformed science. In those cases scientists gather observations and share them using a data substrate, and researchers can verify analyses quickly and (most importantly) pose entirely new and previously unframable questions. The Sloan Digital Sky Survey, the Large Hadron Collider, the Ocean Observatories Initiative, and the iPlant Collaborative have helped turn astronomy, physics, oceanography, and biology into data-driven sciences. The Simplifying Complexity in Scientific Discovery program at the Defense Advanced Research Projects Agency (DARPA, the organization I work for) is also developing mathematical frameworks and tools for scientific data analysis in a variety of domains.

Recent accomplishments by a multidisciplinary team led by the American Museum of Natural History are changing the field of anthropology. The team "datafies" unstructured and semi-structured data from a disparate set of sources and in a diverse set of file formats into a unified knowledge representation schema. The hope is that this effort will enable scientists to pose questions about causation and correlation across multiple linguistic, genetic, and geographic data sources.

DARPA's Big Mechanism program employs machine reading technologies to enable computers to process and understand the results in tens of thousands published cancer biology articles. With this capability, scientists will be able to design new experiments of unprecedented acuity to unlock the larger machinery of the proteins that affect cancer growth. DARPA plans to roll out similar but much larger programs.

We now have the opportunity to reimagine design and manufacturing innovation as a data-driven exercise. The digital thread is simply the digitization of the existing process. To really create a revolution we must widen our aperture and rethink the basic nature of design and manufacturing activity in the light of the revolution in data and computation.

In this new thinking, the data ecosystem is the collective memory of the complete output of a project, from conception to post-production and lifecycle activity for its artifact. It must encompass the dead ends as well as the amazing insights; the unbuilt

The digital thread is simply the digitization of the existing process.

alternatives and the simulation tests for prototypes; the information arcs traced out in the course of design and manufacturing process; the consumer reviews and in-service information feeds from devices in the field.

Today's notion of the digital thread represents merely one strand in a vaster data substrate that is the landscape of the creative activity associated with design and manufacturing.

In this vision, data is the basis for all design, manufacturing, and life-cycle activities. New artifacts are produced out of information from—and interaction with—the data substrate. Production and manufacturing are the physical realizations of information on this substrate. Data is not a mere product of product of a life cycle—it is the information that gives rise to these activities in the first place.

Fundamentally, design and manufacturing are about the transformation of information into something tangible. Think of the process of publishing the magazine you are reading. Printing and binding the magazine is the final manifestation of the writing process that created the articles, the marriage of text and images via production software and the creative and business decisions made by dozens of professionals. The physical artifact of the magazine is all of that information.

This will become increasingly true of every manufactured object. 3-D printers already enable the rendering of objects not just as physical artifacts but as computer files containing all of the information necessary for their production. As advanced manufacturing becomes more prevalent, products will be seen as the physical embodiment of a vast sea of data containing

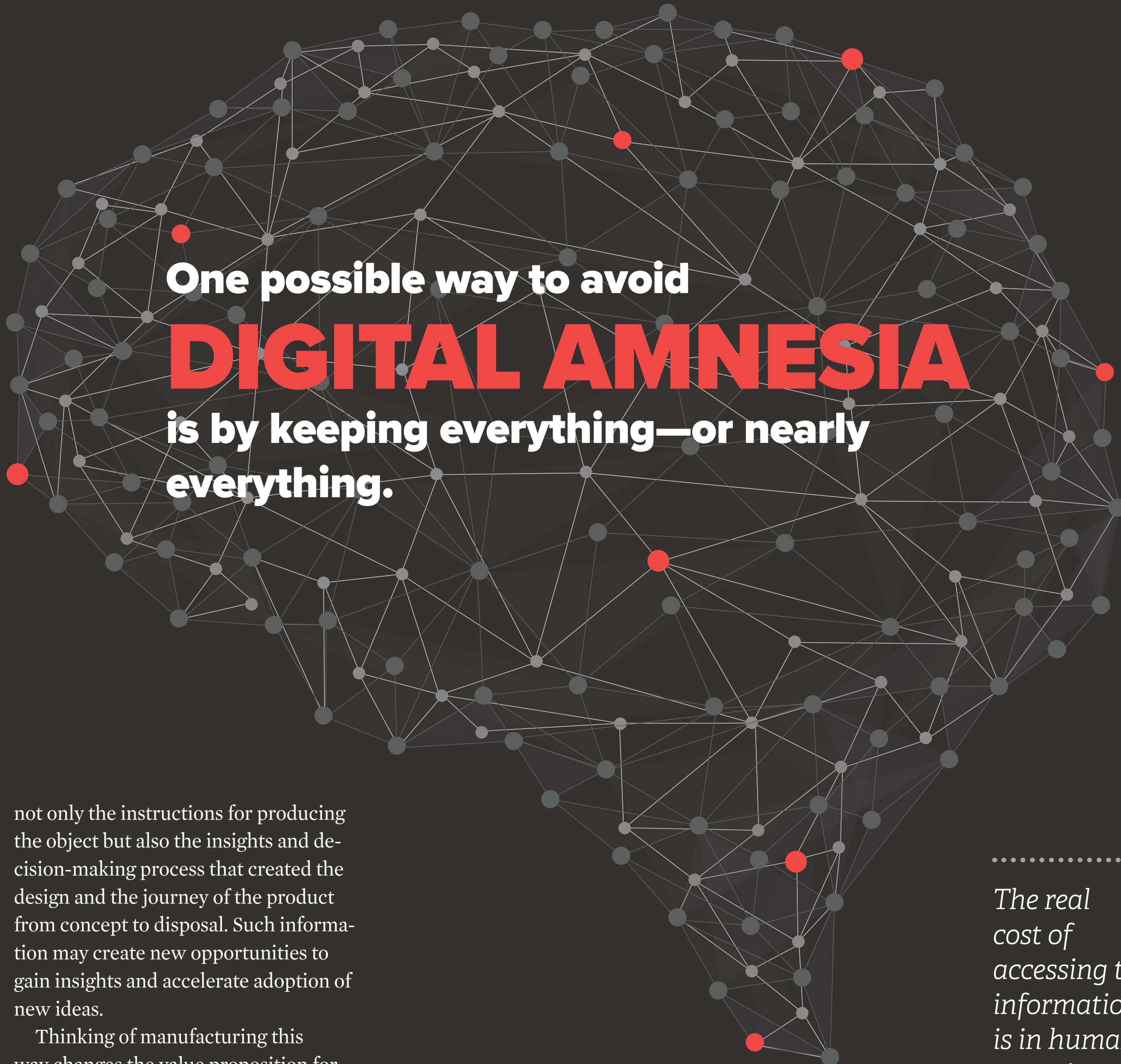
In this new thinking, the data ecosystem is the collective memory of

The **COMPLETE OUTPUT OF A PROJECT,** from conception to post-production and lifecycle activity for its artifact

The **DEAD ENDS** as well as the amazing **INSIGHTS**

The **UNBUILT ALTERNATIVES** and the **SIMULATION TESTS** for prototypes

The **INFORMATION ARCS** traced out in the course of design and manufacturing process, including consumer reviews and in-service information feeds from devices in the field



One possible way to avoid DIGITAL AMNESIA is by keeping everything—or nearly everything.

not only the instructions for producing the object but also the insights and decision-making process that created the design and the journey of the product from concept to disposal. Such information may create new opportunities to gain insights and accelerate adoption of new ideas.

Thinking of manufacturing this way changes the value proposition for data. Too often today, organizations place value only on highly rarified and filtered information: the Six Sigma data, the electronic build record, geometric dimensioning and tolerancing of the design specification, and the final digital thread. With data-driven innovation, however, unexpected value may come from anywhere, including data sets that capture normal, day-to-day activity. As information storage improves to the point where it is limitless and free, we can consider the implications of capturing every bit of data produced at every point in a product's lifecycle.

The real cost of accessing this information is in human attention.

That might seem like overkill, but I think engineering and manufacturing enterprises will recognize that all product lifecycle data is potentially valuable, from requirements gathering to performance monitoring and evaluations of in-service product. Capturing the exploratory process at the beginning of the design process will have an important impact on designers, especially when all the wandering branches of thought throughout the design process can be replayed. Access to that kind of information will turn design into a process of discovery and exploration akin to data-driven science.

Consider the problem currently challenging the community concerning the acceptance and adoption of new materials and manufacturing processes, especially those based on additive manufacturing. Our existing science behind subtractive manufacturing is based on more than a century of work in metallurgy and mechanical engineering. We can accurately predict, for example, the properties of rolled Ti-6Al-4V with great confidence, but additive processes enable us to create entirely new, complex, non-homogeneous materials. Methods for predicting properties of what we can now create cannot possibly be based on exhaustive analysis of physical test coupons. Rather, reaching new material configurations and synthesizing material architectures to satisfy complex, multi-physics design constraints will require new data and computational methods.

Old notions of qualification and certification will yield to those based on data analytics using the sparse sampling of new physical tests, as well as computational observations and predictions. The implications for design tools are significant, and this is but one of the topics being explored in DARPA's new Transformation Design, or TRADES, program.

That vision of design requires engineers, designers, and manufacturers to reconsider some long-held beliefs about best practices. Before we can embrace the future, we first have to let go of the past.

For instance, we must resist the natural engineering tendency to insist that this cornucopia of data should be stored in enduring, standard, digital formats. That is an unachievable, even quixotic goal. Rather than wait for one uber-format, we should harness exponential progress in computing and information science. Continuing improvements in tools for data management, information extraction, schema learning, and machine reading will change the entire calculus around data standards and formats.

We will also have to learn to recognize great ideas wherever they emerge. Tools that can extract the expertise embedded in the data will enhance everyone's capabilities and melt the distinction between expert and amateur. In areas such as finance, commerce, and entertainment, well-nourished computational engines already are yielding astonishing, previously unforeseeable results and unleashing creativity, turning novices into gurus.

Engineering enterprises and their design-to-manufacture partners also must start to exchange ideas and learn from each other. Too much data today is undiscovered or lost to memory, the net asset value of data is lessened, and learning from past innovations becomes difficult, if not impossible. By sharing ideas and information, designers and manufacturers can avoid wasteful design iterations and higher costs while retaining relevant data for post-production activities and new product development.

One possible way to avoid digital amnesia is by keeping everything—or nearly everything. There is real value in the informal information found in engineering notebooks, and there are certainly discoveries that have been lost due to fading memories or deteriorated and destroyed records. Today, with the price of storage plunging, the real cost of accessing this information is in human attention. It is not economically viable, or even feasible, to sift through and accurately curate the data; this must become a job for software. Technologies for doing this automatically are improving exponentially.

We also have to find ways to accept data that is uncertain or potentially unreliable. The key here is to develop the means to quantify the data's utility and track its use (sometimes called provenance or pedigree) over time. This sort of thing is done now with product reviews and scientific datasets. Data's value is not static, and its utility is often discovered or even enhanced over time. The highest quality data can be tracked and tagged.

In time, sufficiently advanced computer-assisted engineering design should enable a kind of digital serendipity. Instead of simply interrogating data to find something specific, we can engage in a more free-form exploration of data that enables discovering the unexpected. That new approach can be viewed as a form of intelligence amplification, where the strategic application of computation and data becomes the key to accelerate scientific discovery, design creativity, engineering proficiency, and other forms of innovation. That sort of computationally enhanced thinking can lead us on a journey that one could not take by oneself; it can lead down paths never imagined or otherwise discoverable.

Far more significant than simply increasing the pace of design iterations, designs themselves can be greatly improved, thereby greatly reducing the rate at which a better design is achieved.

Establishing the rightful and more prominent role of data in engineering, creating a rich and accessible data substrate, and nurturing computational engines will remove unnecessary entry conditions to the design process. As with software development, the future belongs to the designer, not the technician. A larger and more diverse population will be able to participate in the creative process.

But we aren't there yet. The current state of manufacturing design is grounded in 200-plus years of history during which that activity was viewed through the eyes of physics and mathematics, or even as branches of applied physics and mathematics. Computation and data are newcomers. Rethinking existing problems around the notion of algorithm and the abundance of data will require us to discard many long-held beliefs in the light of the new paradigm created by computing machines.

Computer scientists are developing solutions that might enable this transition, but enterprises need to commit to underlying processes and cultures that will truly affect change. The results will be worth it. Let's get started. **ME**

WILLIAM REGLI is deputy director of the Defense Advanced Research Projects Agency's Defense Sciences Office. He may be contacted at regli@darpa.mil.

SAFETY

BY KATHRYN HYAM & PATRICIA REDDINGTON

METROPOLITAN AREAS ARE CONSTANTLY UNDER CONSTRUCTION. OLD BUILDINGS GET TORN DOWN AND NEW, EVEN TALLER ONES SPRING UP TO REPLACE THEM. FROM ONE YEAR TO THE NEXT, THE SKYLINE IS TRANSFORMED. FOR COMMUTERS, SUCH AS THE ASME EMPLOYEES WHO WORK AT OUR HEADQUARTERS AT 2 PARK AVENUE, ALL THAT CONSTRUCTION BARELY REGISTERS.

In recent years, for instance, a corner near the ASME headquarters in Manhattan, past which many ASME employees have to walk each day to catch their trains home, has been the scene of constant activity as two tall buildings have been erected. And while the construction created a bit of inconvenience as pedestrians dodged under scaffolding, it's likely that no one stopped to wonder at the cranes, hoists, and other equipment moving 100 feet overhead.

It's the same for motorists driving through road construction sites or past facilities loading containers onto ships or rail carriages. Cranes and other heavy-lifting machines are such a part of our everyday lives that many of us probably don't even realize how many we see in a given day.

OVERHEAD

For 100 years, ASME's B30 standards have worked to ensure that cargo and construction cranes are used safely.

In a way, that's too bad, since cranes are essential to the maintenance and expansion of modern metropolitan areas. Cranes not only help build the infrastructure we use to work and travel through, but they are critical parts of the containerized cargo system that is the basis of the 21st century supply chain. Cranes, derricks, hoists, and similar lifting equipment move equipment in factories, transfer inventory into and out of warehouses, pick up metal in scrap yards, and sometimes lift objects in our own backyards.

One reason why we can live so easily with cranes is because we trust that they will be used safely. ASME plays an essential role: Beginning in 1916, ASME has developed a code of safety standards, now known as B30, which have helped enable industry to enforce the best practices while reflecting the latest technological

Working on an ASME B30 committee is often invigorating, generally satisfying and at times patience-building. The time and energy given to this well-designed consensus process is always worthwhile because of the committee folks you get to work with and the industries that you get to work for.

— Mike Parnell
ITI-Field Service

Participation in the ASME B30 consensus standards writing process has been one of the most personally rewarding activities I have ever been part of. Where else can an individual interested in promulgating safety in the workplace aid in improving an entire industry while working hand in hand with many knowledgeable and respected persons with a wide breadth of expertise? The end result of the hundreds of hours of effort is multiple safety standards that address, literally, all phases of the load-handling field of endeavor.

— Larry Means
Means Engineering

Tower cranes, such as these working to construct a bridge, are critical machines for building and upgrading infrastructure.

advances. Today ASME publishes 28 volumes of B30, with additional ones in development, under the title *ASME B30 Safety Standard for Cableways, Cranes, Derricks, Hoists, Hooks, Jacks, and Slings*, with the assistance of over three hundred volunteers from industry and government, who participate on the standards committee and subcommittees.

As we celebrate the 100th anniversary of the B30 codes, it is worth looking back on a bit of its history.

CRANES IN HISTORY

Lifting machines represent some of the earliest technology humankind developed. For example, historians know that hoists and cranes were used by the ancient Greeks, both for construction and in theaters to lift actors playing the gods. While the earliest cranes were powered by men or work animals pulling on ropes, later cranes employed the use of human-powered treadwheels, which permitted the lifting of heavier weights. Harbor cranes, for instance, were introduced in the Middle Ages to move cargo and help construct ships

The earliest cranes were made from wooden beams. But new materials were introduced in the late 1700s, during the first Industrial Revolution. Iron and steel parts and steam power enabled cranes to increase their loads and work rates—and paved the way for the adoption of the factory systems. The boom in the amount of goods produced by factories and the revolution in transportation created by steamships and railways meant that the use of cranes, hoists, and other lifting equipment expanded like never before.

Unfortunately, the growth in crane use raced ahead of the guidelines for their safe design and operation. The people who used lifting equipment on the job—dockworkers, railroad yardmen, and factory workers—were suffering injuries due to unsafe operation or designs. In the first decades of the 20th century, various stakeholders—ranging from the Locomotive Crane Manufacturers Association and the Association of Iron and Steel Electrical Engineers to federal agencies such as the Department of Navy and the U.S. Department of Labor—began to press for standards to enhance safety.

ASME played a key role in this movement.

In 1915, nine ASME members, led by John Price Jackson, dean of the engineering school at Pennsylvania State College, were tasked with examining the best practices in crane operations and how to promote them throughout industry. At the Society's 1916 annual meeting that group, the ASME Committee on the Protection of Industrial Workers, presented an eight-page document, *Code of Safety Standards for Cranes*. A summary of that document, published in the November 1916 *Journal of ASME*, listed 40 rules for general construction, 22 rules for operation, six rules for the floormen who signal to the operators, and six for repairmen.

Some of these seem obvious now—"Operators should not eat, smoke, or read while on duty"—but were revolutionary at the time. The section about construction addressed concerns such as the material and design requirements for the cranes' structural components, and other equipment. It also required many of the common safety features that we take for granted, such as mandating the construction of footwalks, platforms, and railing to allow for safe crane access, and requiring clear and visible marking of the hoist capacity to avoid potential overload.

Other sections mandated regular inspections of the crane for loose parts or defects and introduced the first standard for manual hand signals given by signalpersons on the floor to operators. Hand signals are used by signalpersons to help control the load's movement. In factory settings or in busy dockyards, voices are lost in the din; that makes the visual communication carried via standardized hand signals crucial to ensuring safe and efficient operation. The hand signals developed in 1916 unambiguously communicate to the operator whether to hoist or lower the load, and the direction and speed the load should travel.

Those standard hand signals are still used today and the ASME hand signal charts have become the industry standard used worldwide.

EXPANDING THE SCOPE

The presentation of the 1916 code was not the last word on crane safety, but the beginning of a larger process for developing standards for use by manufacturers, users, insurance carriers, and regulatory authorities. And the scope expanded, too, from the electric traveling cranes, jib cranes, monorail cranes, and hand-powered cranes specifically mentioned by the Committee on the Protection of Industrial Workers to cover devices as varied as overhead gantry and locomotive cranes, derricks, hoists, slings, and chains.

Within 10 years of the issuance of 1916 code, a Sectional Committee was formed and work began expanding the 1916 Code, resulting by 1943 in the first two standards in the current series that would be developed under ASME's B30 Committee activity. The *B30.1 Safety Code for Jacks* was developed to provide guidance for the use of all portable manually operated jacks (except those that are supplied with automobiles, which ASME has separate standards for).

The 1943 edition of the B30.1 covered several different kinds of jacks, including lever and ratchet, screw, and hydraulic, all of which are used to lift and lower loads. The second volume published in 1943—*B30.2 Safety Code for Cranes, Derricks and Hoists*—covered the remaining types of commonly used cranes in industry at the time. That included overhead and gantry cranes, jib cranes, mobile cranes, derricks, hoists, slings, chains, and ropes.

Over time, stakeholders realized that the B30 standards needed to better reflect the changes in design, advancement in techniques, and general safety interests of labor and industry. In 1962, the format of the standard was revised to allow separate B30 volumes to cover different types of equipment. In that way, each B30 volume could be expanded to cover additional areas beyond construction and operation requirements to deal with installation, testing inspection, and maintenance requirements.

For example, in 1968 the committee published the first B30.5 cranes standard to handle crawler, locomotive, and truck cranes. ASME and the Naval Facilities Engineering Command jointly sponsored the committee's work to make that new volume. Around that time, the original committee swelled from 39 to 57 members and alternates representing 35 organizations, including the Factory Mutual Engineering Corporation, the American Insurance Association, and the AFL-CIO. That first 24-page volume made possible the safe use of mobile cranes, which are a common

I joined ASME while still in college and volunteered for many of their projects and activities. I got involved with the B30 committee about 15 years ago in order to increase my knowledge and capabilities, and I have learned much since then. I have been able to give back to the committee and their members through my efforts to improve the standard and by sharing the knowledge I have gained through my different experiences.

— Phil Boyd
The Boeing Company

If we as an industry don't police ourselves, someone else will. We can do a better job of it.

— David Duerr
2DM Associates

The consensus process B30 uses, which includes so many different subject-matter experts, and ASME's Policies and Procedures, guarantees the development of quality standards that can confidently be used by those in the crane and crane-associated industries.

— Gene Owens
Consultant

I have worked with B30 type of equipment for 34 years using the B30 standards and have now been involved with B30 Committee work since 2001. Working with the various members of the different committees has allowed me to incorporate my experiences and expertise into helping form the standards used in this industry to make the equipment we cover safer for the people using and operating them. It has been an honor to work with this group of dedicated individuals for the betterment of our society.

— **Alan Egging**
National Oilwell Varco

slight along freeways for bridge construction or building construction. The B30.5 today is one of the most widely utilized ASME B30 volumes.

Individual volumes are not intended to be a step-by-step design guide, but each one recommends actions intended to enhance safety during the construction, testing, inspections, maintenance, and operation of cranes. Safe and reliable operation of load-handling equipment involves paying close attention to such factors as design, selection, installation, erection, dismantling, and use of the load handling equipment.

The final design needs to meet performance-based requirements such as passing the load test requirements or following the marking requirements outlined in the B30 volumes. The volumes also outline requirements for regular inspection and maintenance to ensure that equipment will continue to operate safely within their design parameters throughout the life of the crane.

In addition, the B30 volumes also outline requirements for safe operation of the equipment by defining criteria for operator qualifications and providing operation guidelines and operating practices for attaching, holding and moving the load. Standard hand signals continue to be outlined for the equipment, and special guidance for operating in the vicinity of power lines is also provided. In recognition that the operator may not be in charge of all aspects of the job site or equipment maintenance, B30 volumes have recently begun to include specific responsibilities to the defined roles of management, crane owner, crane user, site supervisor, and lift director.

CONTINUING IMPROVEMENT

The B30 standards are developed and maintained by industry expert volunteers. Instead of a government mandate and funding, the ASME B30 Safety Standard for Cableways, Cranes, Derricks, Hoists, Hooks, Jacks, and Slings Committee that maintains these volumes operates under well-defined and transparent operating procedures accredited by the American National Standards Institute. ANSI accreditation signifies that the procedures used by standards developing organizations meet the Institute's requirements for openness, balance, consensus, and due process.

All standards are developed in an environment that is accessible and responsive to the all stakeholders—including the public—who are provided an opportunity to submit requests for revision and comment on proposed

THE 28 VOLUMES OF THE ASME B30 SAFETY STANDARD

1943 - B30.1 Jacks, industrial rollers, air casters, and hydraulic gantries

1943 - B30.2 Overhead and gantry cranes (top running bridge, single or multiple girder, top running trolley hoist)

1975 - B30.3 Tower cranes

1973 - B30.4 Portal and pedestal cranes

1968 - B30.5 Mobile and locomotive cranes

1969 - B30.6 Derricks

1971 - B30.7 Winches

1971 - B30.8 Floating cranes and floating derricks

1971 - B30.9 Slings

1975 - B30.10 Hooks

1973 -B30.11 Monorails and underhung cranes

1975 - B30.12 Handling loads suspended from rotorcraft

1977 - B30.13 Storage/

Floating cranes such as this are mainly used as support vessels during the construction of offshore structures.

revisions to volumes prior to publication.

Within the committee framework managed by ASME, the B30 standards committee is always looking to incorporate the industry's latest technological advances and best practices.

For example, in 2012 a new volume, *B30.29 Self-Erecting Tower Cranes,* was issued on the basis of industry advocacy that those machines, commonly used in skyscraper construction, did not easily fit into the operational criteria of either a mobile or tower crane. Another recent addition, the *B30.28 Balance Lifting Units,* was requested by industry to cover devices used in factories or warehouses to help position and maneuver heavy items.

While the basic principles of ancient machines are still applicable in many modern lifting devices, advances in materials and technology have allowed for cranes to be adapted to aid in accomplishing difficult and unusual tasks. The lifting capacity of the largest cranes has grown to more than 2,500 tons—the equivalent of lifting 1,000 cars. Behind the scenes cranes are at work in harbors and factories around the world moving the consumables and products that we rely on for our day-to-day food, energy and shelter needs. Some cranes are even used to erect other cranes which then go on to build the skyscrapers that dot our skyline.

Mobile cranes lift the Space Shuttle *Endeavour* onto its overland transporter at Los Angeles International Airport.

Even with all these changes, ensuring safety is just as important today as it was in 1916, when the ASME Committee on the Protection of Industrial Workers first presented its proposed code. Thanks to the hundreds of dedicated volunteers donating their time and expertise to the continual improvement of the B30 volumes, ASME is leading the way in helping to ensure cranes can be a common and essential part of the everyday landscape. ME

KATHRYN HYAM is a project engineering advisor with ASME Standards & Certification, Safety Codes and Standards. **PATRICIA REDDINGTON** is Director of Safety Codes and Standards.

I became involved with the B30 committee to stay at the leading edge of safety requirements for the crane and rigging industry. I also wanted to extend my network of colleagues and experts in the industry.

— **David Moore**
Unified Engineering

retrieval (S/R) machines and associated equipment

1979 - B30.14 Side boom tractors

1973 - B30.15 Mobile hydraulic cranes (withdrawn 1982)

1973 - B30.16 Overhead hoists (underhung)

1980 - B30.17 Overhead and gantry cranes (top running bridge, single girder, underhung hoist)

1987 - B30.18 Stacker cranes (top or under running bridge, multiple girder with top or under running trolley hoist)

Gantry cranes handle the loading and unloading of cargo containers at the world's ports.

1986 - B30.19 Cableways

1985 - B30.20 Below-the-hook lifting devices

1989 - B30.21 Lever hoists

1987 - B30.22 Articulating boom cranes

1998 - B30.23 Personnel lifting systems

2008 - B30.24 Container cranes

1998 - B30.25 Scrap and material handlers

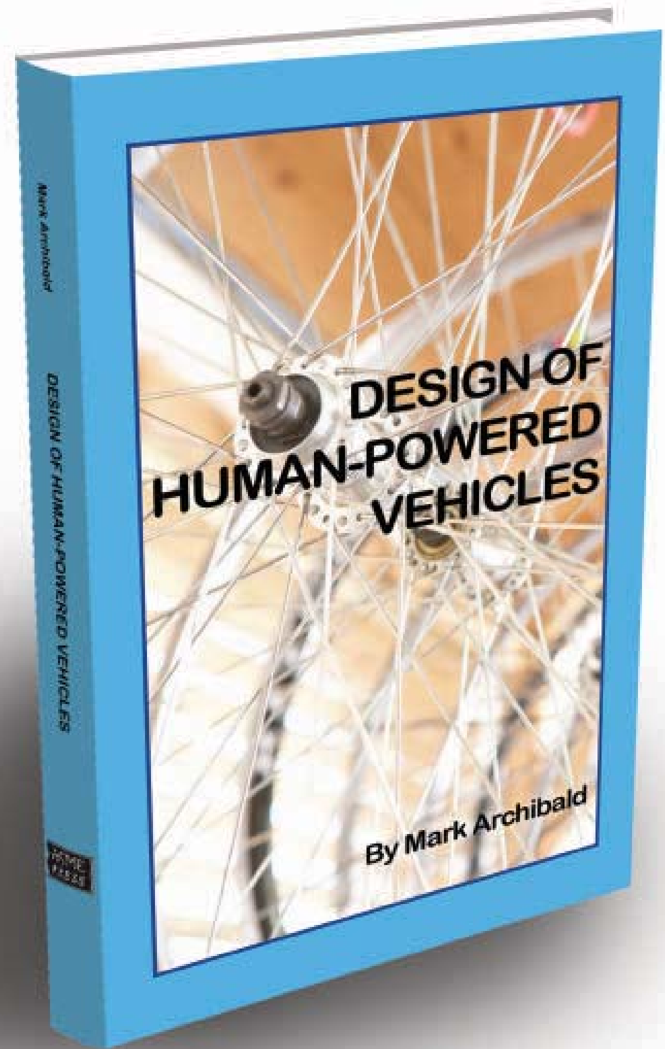
2004 - B30.26 Rigging hardware

2005 - B30.27 Material placement systems

2010 - B30.28 Balance lifting units

2013 - B30.29 Self-erecting tower cranes

B30.30 Ropes (under development)



FEATURED

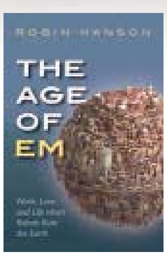
DESIGN OF HUMAN-POWERED VEHICLES

MARK ARCHIBALD

ASME Press, Two Park Avenue, New York, NY 10016. 2016.

Human-powered vehicles come in a lot of shapes and sizes—from ancient galleys to modern skateboards. Today, however, the term most often refers to high-performance semi-recumbent bicycles and tricycles, especially those used in competitions. Mark Archibald focuses on the design of these high-end machines, discussing such factors as how to reduce the aerodynamic drag and increase the efficiency of the drive chain. He also looks at limits of human physiology as well as the key advantage of HPVs. “No other option can provide quantifiable reduction in air pollutants and greenhouse gas emissions with available and affordable technology that uses existing infrastructure,” Archibald writes. “HPVs are, for the present, critical to achieving a sustainable transportation system.”

300 PAGES. $79; ASME MEMBERS, $63. ISBN: 978-0-7918-6110-3.



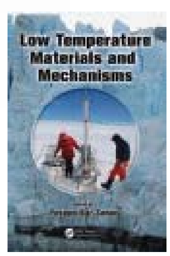
THE AGE OF EM: WORK, LOVE AND LIFE WHEN ROBOTS RULE THE EARTH

Robin Hanson

Oxford University Press, 198 Madison Ave, New York, NY 10016. 2016.

Hanson teaches economics at George Mason University and is a research associate at Oxford’s Future of Humanity Institute, which was set up to study existential risks to humanity. The risk Hanson writes about in his new book is that of artificial intelligence—the “em” in the title refers to brain emulations. Robots controlled by computers that are essentially copies of human brains (something Hanson says may appear by the end of the century) would greatly accelerate economic output, but would also make human labor superfluous. Hanson doesn’t spend much time looking at the effects on humanity, however, but rather examines this future from the em point of view: how they would live, love, laugh, and see their place in the world.

368 PAGES. $34.95. ISBN: 978-0-1987-5462-6.



LOW TEMPERATURE MATERIALS AND MECHANISMS

Yoseph Bar-Cohen, editor

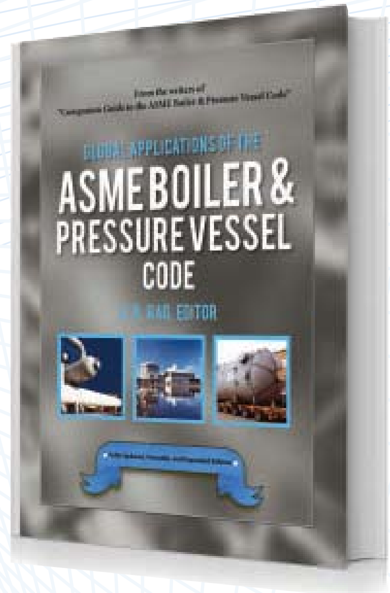
CRC Press, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487. 2016.

While many mechanical engineers have to master the properties of materials at high temperatures (think of the insides of gas turbines) this book provides a broad perspective on low temperature materials and their applications. Bar-Cohen, a senior research scientist and group supervisor of advanced technologies at the Jet Propulsion Laboratory, brings together authors who cover a diverse range of concerns, from how medical and biological technologies operate at extremely low temperatures to the special requirements of space probes that travel to the coldest corners of the solar system. Of special interest are the sections dealing with drills, actuators, and sensors for use in Arctic regions.

500 PAGES. $159.95. ISBN: 978-1-4987-0038-2.

NEW FROM ASME PRESS

GLOBAL APPLICATIONS OF THE ASME BOILER & PRESSURE VESSEL CODE



K.R. Rao, Editor

This comprehensive work written by ASME Codes & Standards experts was originally published as part of Volume 3 of the *Companion Guide to the ASME Boiler & Pressure Vessel Code.* This fully updated and expanded volume is now a stand-alone publication that addresses global applications of the ASME B&PV Code.

The impact of globalization and inter-dependency of ASME B&PV Code is recognized in this volume, by inclusion of several countries that own and operate nuclear reactors or have nuclear steam supply vendors and fabricators that use ASME B&PV Code Sections I through XII. This information is meant to benefit international users of ASME Codes with authors covering East and West European countries, Africa, Asia, in addition to the USA and Canada.

This book is divided into five parts with 917 references.

- The first part addresses West European countries such as Pressure Equipment Directive (PED) of the European Community, Canada, France, United Kingdom, Belgium, Germany, Spain and Finland.
- Part two addresses "Global Applications of ASME Codes in Central and Eastern Europe". Country Codes covered in this part are Russia, Czech and Slovakian Codes and Hungary.
- Part three covers the Codes and Standards used in the Nuclear Industry in the Republic of South Africa.
- Nowhere in the world is nuclear power activity so much in evidence as in Asia. Global Applications of the ASME B&PV Codes of the Asian Countries is covered in Part Four which includes Japan, Korea, Taiwan, India and China.
- Part five provides "Special Topics", worthy for users of Global Applications of ASME Boiler and Pressure Vessel Codes.

An important feature of this publication is once again, as in the previous editions, the inclusion of all author biographies and an introduction that synthesizes every chapter, along with an alphabetical listing of indexed terms.

500 pages

Hardcover

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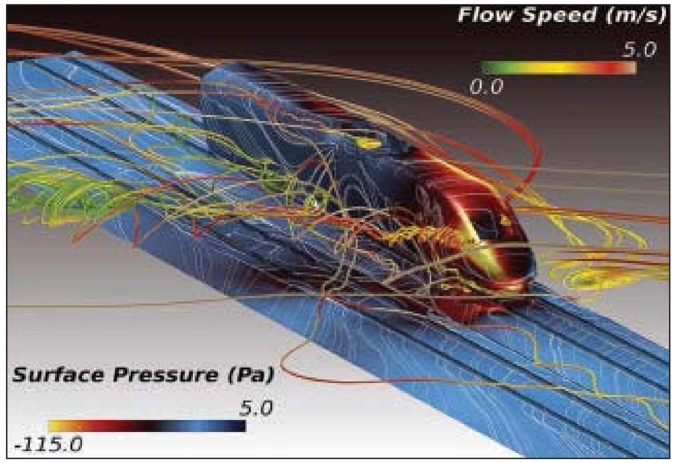
ASME
SETTING THE STANDARD

The American Society of Mechanical Engineers (ASME)

SIMULATION FOR CAE

ALTAIR, TROY, MICH.

HyperWorks 14.0 is the latest release of Altair's open architecture CAE simulation platform. The new version features expanded optimization and nonlinear solver capabilities and accelerated meshing, assembly, and graphics. For instance, the application's HyperMesh function has a new part and assembly workflow to enable data to move directly from product data management to data structures. FEKO, the company's software for electromagnetic simulation is now fully merged into HyperWorks with added features to reduce modeling and computation time. Combined with the new high-velocity graphics engine, HyperMesh



14.0 is up to 15 times faster than previous versions for large finite element models with solid elements and up to 60 times faster for geometry models.

DIE CASTING SIMULATION

CD-ADAPCO, MELVILLE, N.Y.

STAR-Cast v11.02, the casting simulation add-on for STAR-CCM+, features a new high pressure die casting module to provide casting engineers with a tool for designing stronger and lighter casted parts. STAR-Cast integrates CAE technology with the detailed models required for casting, enabling the simulation of interactions between molten metal and air, with the intent of enabling a better understanding of the complete high pressure die casting process and the discovery better designs. STAR-Cast v11.02 also incorporates enhancements to streamline simulation workflow, such as enabling easier material handling and manipulation, including a brand-new material database builder for the integration of proprietary materials into the customer's material database.

WIREFRAME DRAFTING

ASHLAR-VELLUM, AUSTIN, TEXAS

Ashlar-Vellum announces the release of Graphite v10, the latest version of its intuitive 2-D/3-D CAD wireframe drafting package for that lastest versions of Mac and Windows operating systems. New features include remembering the tool palette and dialog box positions independently for every screen size used, including single and dual screen configurations, and operating the draw control order from either the layers dialog box or the arrange menu. The application's DXF/DWG import capability supports AutoCAD 2016 files. Raster imaging handling has also been improved.

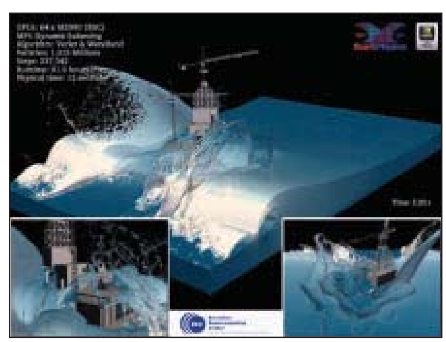
PROTOTYPING PLATFORM

ESI GROUP, PARIS.

ESI, a provider of virtual prototyping software and services, has released the latest version of its multi-domain simulation platform, Visual-Environment 11.5. The platform manages simulation processes in a single unified environment, from pre- and post-processing to meshing, viewing results, and automating tasks. Visual-Environment 11.5 now supports Modelica-based systems modeling and simulation, and virtual product assembly. That enables systems modeling architects and engineers to manage the traceability between requirements and models, and to virtually connect complex systems, accounting for different physics. The new version also integrates the Modelica Standard Library and is compatible with third-party libraries and ESI specific Modelica libraries. In addition, the new ESI-Player application for Windows and iOS phones and tablets enables engineers to visualize their ESI result files remotely.

HYDRODYNAMICS MODELING

ENVIRONMENTAL PHYSICS LABORATORY, UNIVERSIDADE DE VIGO, SPAIN.



DualSPHysics v4.0 is the latest release of an application based on the smoothed particle hydrodynamics model named SPHysics. The code was developed to study free-surface flow phenomena where Eulerian methods can be difficult to apply, such as waves or the impact of dam-breaks on off-shore structures, and was designed to deal with real-life engineering problems. Wave generation is included in DualSPHysics v4.0, though only for long-crested waves, so that the model can be used to simulate a physical wave flume. Both regular and random waves can be generated. Also, a new post-processing tool computes the force exerted by a fluid onto a solid object. The value of force is calculated as the summation of the acceleration values (solving the momentum equation during interaction between fluid and boundary) multiplied by the mass of each boundary particle.

DATA ACCESS

FARO TECHNOLOGIES, LAKE MARY, FLA.

Faro,a developer of computer-aided measurement and imaging devices, has released version 2.0 of its SCENE WebShare Cloud data-hosting platform. The platform is designed to provide easy-to-use 3-D viewing of as-built data over the Internet without the need for dedicated software or hardware. The system is intended to be used on almost any modern mobile device, including tablet computers and smart phones. The system enables users in fields such as building information modeling, architecture, and construction information management to have immediate access to data about buildings, plants, and construction sites, the company says. WebShare Cloud is closely integrated with Faro's SCENE desktop software, and as a cloud-based service all updates and enhancements are automatically available to any user.

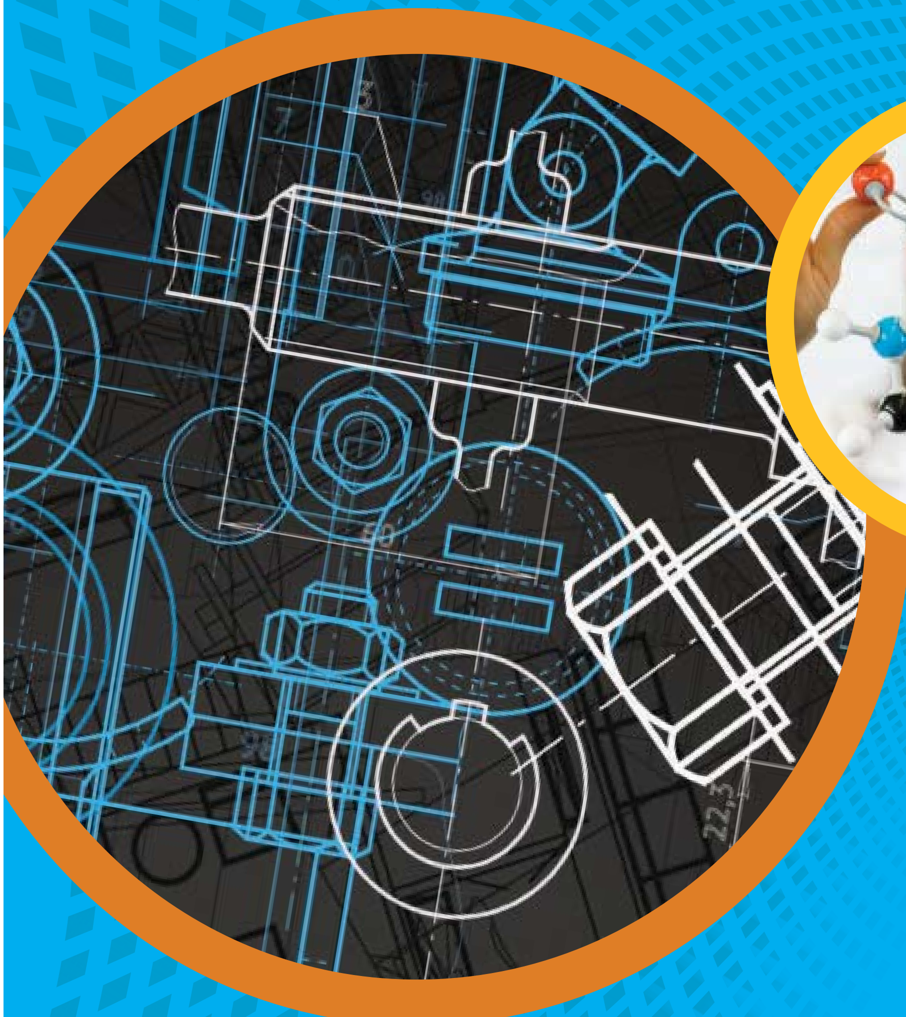
PRINTABLE GEOMETRY

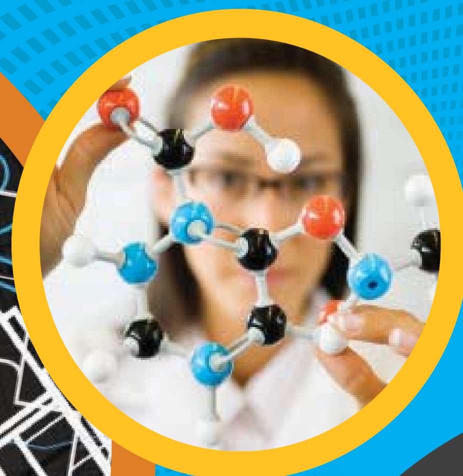
SHAPEWAYS, NEW YORK.

ShapeJS 2.0 is the latest version of the system for generating 3-D printable objects via a simple Javascript program developed by Shapeways, the 3-D printing company. ShapeJS 2.0 has a "rich interface definition" to allow makers and designers to share parametric objects. Design work can be widely reused and easily customized for a variety of situations and contexts. Other new features include a real-time evaluation using Open Computing Language, image-based rendering, protection of 3-D content, and the ability to share objects and parameters using zip format. Because ShapeJS 2.0 taps the graphics processing units of computers to perform functions such as the evaluation of scripts, some operations are now performed 100 times faster than in the previous version. ME

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.





A forum for emerging systems and control technologies.

DYNAMIC SYSTEMS & CONTROL

SEPTEMBER 2016 VOL. 4 NO. 3

HEALTH CARE: SYSTEMS FOR REHABILITATION AND THE ELDERLY

ASME

SUBMIT ARTICLE IDEAS TO:

PETER H. MECKL
PURDUE UNIVERSITY
meckl@purdue.edu
(765) 494-5686

SUBMIT DSCD NEWS ITEMS TO:

DENISE MCKAHN
SMITH COLLEGE
dmckahn@smith.edu

Tentative future issues of *Dynamic Systems & Control Magazine*

December 2016
Autonomous and Connected Vehicles

March 2017
Cyber-Physical Systems

Health Care Systems

The Office of the Actuary in the Centers for Medicare & Medicaid Services estimates that the United States will spend approximately 3.4 trillion dollars on healthcare in 2016, with that number projected to rise to 4.7 trillion dollars in 2022. As a percentage of GDP, US healthcare spending jumped from 8% in 1980, to 14% in 2000, and to almost 18% in 2010. The US has seen a greater increase in healthcare expenditures versus GDP than other developed countries, raising major concerns for the future of the US economy. Extensive debate among policy makers has produced widespread agreement that the US must move towards efficient utilization of existing channels for healthcare delivery, effective advancement of technology to provide access to healthcare data and automated services, and implementation of novel processes to control costs.

While new ideas are emerging to improve operation of the current healthcare system, shifting demographics are also altering the underlying healthcare landscape. Consider that people over 65 currently account for 14% of the US population, but that this ratio is expected to rise to around 21% by 2040. A 2011 report to Congress estimated the cost to Medicare of hospital services at $1,805 per day, versus only $145 per day for home care. Thus the aging of the population is driving a reconsideration of the standards for healthcare delivery to the elderly, with a customized, effective, and affordable combination of in-home and hospital-based solutions becoming increasingly attractive.

These challenges call for creative approaches, incorporating optimization, distributed decision-making, autonomy, and connectivity. There are growing opportunities to integrate engineering methodology with operations research, economics, human factors, and policy making. In particular, as exemplified by the articles in this issue, there is an important opportunity for dynamic systems and control researchers to extend traditional tools to healthcare applications, based on appropriate incorporation of human physiology and psychology.

The first article, by Dixon and Bellman, considers a system combining electrical stimulation and motor-assist to maintain physical condition in individuals experiencing leg muscle dysfunction caused by neurological impairment. The authors take a control-systems perspective, with the goal of providing a stable response – that is, a sustainable cycle of muscle activity. The second article, by Marinho, et al., considers how robots may prolong the ability of the elderly to remain independent in their own homes. The authors stress a human-centric approach, to ensure safety and user acceptance, including robot movements designed to induce a desired emotional response. Both articles point towards a great need for additional contributions from the dynamic systems and control community.

We greatly appreciate the authors' contributions to this issue in their busy schedules, and thank both Denise McKahn who compiled the news section of this issue and ASME staff for the hard work they put behind the scenes to deliver this issue.

Last but not least, we would like to thank you for your support of the Magazine, and request that you contact the Editor, Peter Meckl **(meckl@purdue.edu)** for any ideas for future issues.

Jordan M. Berg, PhD
Rifat Sipahi, PhD
Guest Editors, *DSC Magazine*

COVER IMAGES: (TOP) CHRISTIAN COUSIN , (BOTTOM) CHRISTOPHER WIDDOWSON

AWARDS AND ANNOUNCEMENTS

We would like to take this opportunity to celebrate the achievements of our ASME DSCD members!

Simona Onori recently received the 2016 Emerging Leader Award from the 2016 Energy Inc. Summit. This industry focused conference recognizes the achievements of leaders in the energy industry. Dr. Onori is an Assistant Professor in Automotive as well as Electrical and Computer Engineering at Clemson University.

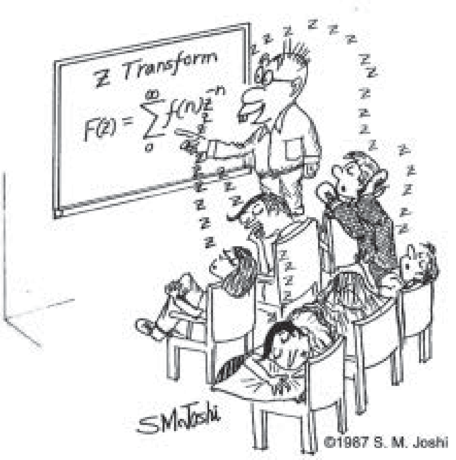
Marcia O'Malley and her team of researchers recently showcased their research on Capitol Hill at the Congressional Robotics Caucus's National Robotics Initiative. Their research aims at helping stroke survivors to "think" their disabled limbs into motion. Dr. O'Malley is a Professor of Mechanical Engineering and Director of the Mechatronics and Haptic Interfaces Lab at Rice University.

Junmin Wang was recently elected Fellow of the Society of Automotive Engineers and ASME. Dr. Wang, Professor of Mechanical and Aerospace Engineering at The Ohio State University, is recognized for his pioneering role in the investigation and development of new control methods that allow substantial advances in the performance of engines, after-treatment systems and the whole vehicle.

Kira Barton (2015) and **Chinedum Okwudire** (2016) have both been selected to receive the Society of Manufacturing Engineers (SME) Outstanding Young Manufacturing Engineer Award. The award recognizes manufacturing engineers, age 35 or younger, who have made exceptional contributions and accomplishments in the manufacturing industry. Drs. Barton and Okwudire are Assistant Professors of Mechanical Engineering at the University of Michigan.

Chinedum Okwudire has been selected to receive the Young Investigator Award at the 2016 International Symposium on Flexible Automation. This award is open to all young investigators, age 35 or younger, working in areas related to flexible automation.

Georgi M. Dimirovski has edited a research monograph, published by Springer-Verlag, entitled "*Complex Systems: Relationship between Control, Communication and Computing*" as Volume 55 in the series "*Studies in Systems, Decision and Control*". This work was produced in co-operation with 84 authors from across four continents. The monograph is organized into five parts: I. Control and Supervision of Complex Networks and Systems; II. Machine Intelligence and Learning Control in Complex Systems; III. Control and Supervision of Complex Mechanical Structures and Robots; IV. Control and Supervision in Multi-agent and Industrial Systems; and V. Novel Control Ideas and Variable-Structure Systems Control.



Control systems cartoons and educational material by Suresh Joshi is freely available at http://ControlCartoons.com

UPCOMING CONFERENCES

2016 IEEE MULTI-CONFERENCE ON SYSTEMS AND CONTROL
Buenos Aires, Argentina NH City & Towers Hotel September 19-22, 2016
http://www.msc2016.org/

THE ASME INTERNATIONAL MECHANICAL ENGINEERING CONGRESS AND EXPOSITION
Phoenix, Arizona Phoenix Convention Center November 11-17, 2016
https://www.asme.org/events/imece

55TH IEEE CONFERENCE ON DECISION AND CONTROL
Las Vegas, Nevada ARIA Resort & Casino December 12-14, 2016
http://cdc2016.ieeecss.org/

THE 2017 AMERICAN CONTROL CONFERENCE
Seattle, WA Sheraton Seattle Hotel May 24-26, 2017 http://acc2017.a2c2.org/

2017 AIM, IEEE INTERNATIONAL CONFERENCE ON ADVANCED INTELLIGENT MECHATRONICS
Munich, Germany July 3-7, 2017 http://www.aim2017.org/

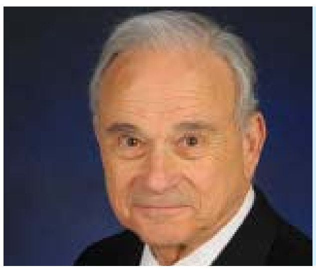
IFAC 2017 WORLD CONGRESS
Toulouse, France July 9-14, 2017 https://www.ifac2017.org/

American Automatic Control Council 2016 Award Recipients

At the 2016 American Control Conference, the American Automatic Control Council announced the following awards to our community members:

RICHARD E. BELLMAN CONTROL HERITAGE AWARD

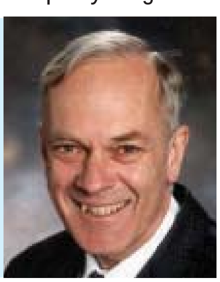
Jason Speyer received the Richard E. Bellman Control Heritage award for his pioneering contributions to deterministic and stochastic optimal control theory applied to aerospace engineering, including spacecraft, aircraft and turbulent flows. The Bellman Award is given for distinguished career contributions to the theory or application of automatic control and is the highest recognition of professional achievement for U.S. control systems engineers and scientists.



Jason Speyer, Professor of Mechanical and Aerospace Engineering at the University of California, Los Angeles.

JOHN R. RAGAZZINI CONTROL EDUCATION AWARD

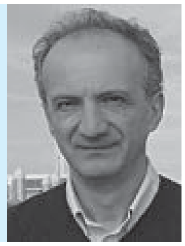
Brian D. O. Anderson received the John R. Ragazzini Education award for his contributions to engineering education through the authorship of widely cited textbooks and mentorship of young control engineers. The Ragazzini award recognizes outstanding contributions to automatic control education in any form.



Brian D. O. Anderson is a Distinguished Professor of the Research School of Information Sciences and Engineering at The Australian National University.

CONTROL ENGINEERING PRACTICE AWARD

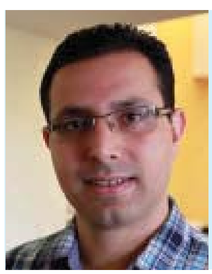
Mrdjan Jankovic received the Control Engineering Practice award for his contributions to vehicle fuel economy and emission improvements using advanced control methods. This award recognizes contributions to the advancement of control practice through the application and implementation of innovative control concepts, methodology, and technology, for the planning, design, manufacture, and operation of control systems.



Mrdjan Jankovic is a Senior Technical Leader in the Control Engineering organization at Ford Motor Company.

DONALD P. ECKMAN AWARD

Javad Lavaei received the Donald P. Eckman award as an outstanding young engineer in the field of automatic control.



Javad Lavaei, Assistant Professor of Industrial Engineering and Operations Research at the University of California, Berkeley.

His research focuses on a wide variety of interdisciplinary problems in control theory, optimization, power systems, distributed computation and networks.

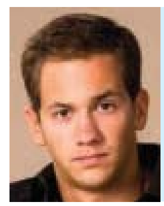
O. HUGO SCHUCK BEST PAPER AWARDS

Scott Moura, an Assistant Professor of Civil and Environmental Engineering at UC Berkeley, and **Hector Perez**, a PhD candidate and Graduate Student Researcher in the Energy, Controls, and Applications Laboratory (eCAL) at UC Berkeley received this award for their ACC 2015 paper titled, "Sensitivity-Based Interval PDE Observer for Battery SOC Estimation".

Sergio Pequitto, a Post-doctoral Researcher in the Electrical and Systems Engineering Department at the University of Pennsylvania, **Soummya Kar**, an Associate Professor in Electrical and Computer Engineering at Carnegie Mellon University, and **George Pappas**, a Professor and Chair of Electrical and Systems Engineering at the University of Pennsylvania, received this award for their ACC 2015 paper titled, "Minimum Cost Constrained Input-Output and Control Configuration Co-Design Problem: A Structural Analysis Approach".

AMERICAN CONTROL CONFERENCE 2016 BEST STUDENT PAPER AWARD RECIPIENTS

Ernst Csencsics, Student Author and Research Assistant, **Rudolf Saathof**, a Post-doctoral Researcher, and **Georg Schitter**, a Professor of Industrial Automation, all from the Vienna University of Technology, received the Best Student Paper Award for their work on the "Design of a Dual-Tone Controller for Lissajous-based Scanning of Fast Steering Mirrors".



Ernst Csencsics, Research Assistant with the Automation and Control Institute, Vienna University of Technology.

The following additional papers were finalists for the Best Student Paper Award:

Soulaimane Berkane (Student Author), **Abdelkader Abdessameud**, and **Abdelhamid Tayebi**, on "Global Hybrid Attitude Estimation on the Special Orthogonal Group SO(3)"

Bala Kameshwar Poolla (Student Author), **Saverio Bolognani**, and **Florian Dörfler** on "Placing Rotational Inertia in Power Grids"

Mohammad Amin Rahimian (Student Author) and **Ali Jadbabaie** on "Learning without Recall from Actions of Neighbors"

Rahul B. Warrier (Student Author) and **Santosh Devasia** on "Inverse Control for Inferring Intent in Novice Human-in-the-loop Iterative Learning".

CYCLING INDUCED BY FUNCTIONAL ELECTRICAL STIMULATION: A CONTROL SYSTEMS PERSPECTIVE

BY WARREN DIXON
PROFESSOR
DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
UNIVERSITY OF FLORIDA

MATTHEW BELLMAN
FOUNDER & CHIEF TECHNOLOGY OFFICER
MYOLYN, LLC

An electric field can be applied to muscle to yield a contraction, generally termed neuromuscular electrical stimulation (NMES). When applied to yield functional tasks, it is more specifically termed functional electrical stimulation (FES). FES is commonly prescribed as a treatment for various neurological disorders (e.g., stroke, spinal cord injury, traumatic brain injury, Parkinson's disease, etc.). Such disorders affect millions of Americans, resulting in costs that exceed $100 billion per year. Common impairments caused by neurological disorders lead to limited physical activity due to muscle weakness, paralysis, and/or loss of limb coordination. In turn, limited physical activity increases the risk of negative secondary health effects such as obesity, poor self-image, diabetes, cardiovascular disease, and other chronic conditions. While current clinical practice typically uses open-loop FES, many researchers are currently focused on closed-loop, computer-controlled FES. In the development of such closed-loop FES algorithms, the musculoskeletal system is modeled as a mechanism comprising links and actuators that are activated by controls and robotics methods executed by a computer interface to the person (i.e., a cybernetic system).

Automated FES methods hold the potential to maximize therapeutic outcomes by self-adjusting to the particular individual, facilitating at-home therapy and enabling effective therapy from less experienced clinicians. Yet, the development of automated FES devices is complicated by the uncertain nonlinear musculoskeletal response to stimulation, including disturbances such as fatigue that are difficult to measure or model. Unfortunately, therapeutic dosage (i.e., intensity and number of contractions) is limited by the onset of fatigue and poor muscle response during fatigue. Specifically, fatigue results in diminished force production and increased delay in the muscle response, leading to inaccurate limb positioning and low musculoskeletal loading. As a result, methods to yield efficient muscle force/torque production (including shared force production by motorized systems such as robotic exoskeletons) and stimulation methods that mitigate fatigue (e.g., asynchronous and other multi-channel stimula-

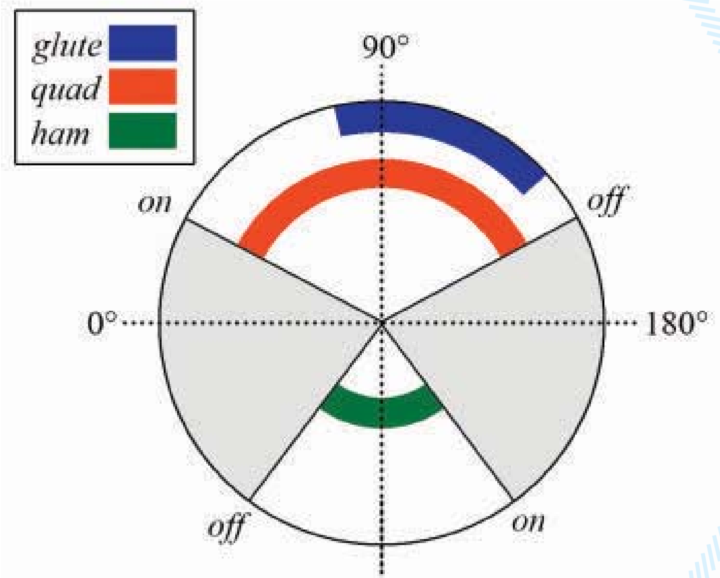


FIGURE 1 Example stimulation pattern as a function of the crank position for the gluteal, quadriceps, and hamstring muscle groups on a single leg. Grey shaded regions indicate sections of the crank cycle where it is inefficient for a selected muscle group to produce torque. Electrical stimulation is turned on and delivered to respective muscles in specified regions and turned off in regions where it is inefficient to produce torque.

tion methods) are the mainstream focus in general FES literature.

A common mode of activity-based therapy utilized clinically is stationary FES-cycling, since it is a low-impact, stable, repetitive exercise that involves coordinated limb motion. FES (often coupled with an electric motor to help turn the cycle crank) is a key enabler for rehabilitative cycling therapies because individuals with neurological disorders often lack sufficient strength and coordination for symmetric, volitional pedaling, making it difficult to achieve and maintain a sufficient workload for target heart rate thresholds and other desired training effects.

FES-induced cycling methods began to emerge in the 1980s. Early FES-cycling studies used open-loop or proportional-derivative feedback control of the stimulation intensity to achieve a desired cycling cadence. Over the past several decades, researchers began using tools from the control systems community to improve FES-cycling performance, including: system identification and pole placement methods for linearized models, robust control methods such as sliding mode control, and intelligent control methods such as neural networks and fuzzy logic.

All of these previous FES-cycling control studies alternated stimulation across different muscle groups according to a predefined stimulation pattern. The stimulation pattern defines the segments of the crank cycle over which each muscle group is stimulated to achieve the desired cycling motion. **Figure 1** depicts an example stimulation pattern from [1] wherein the quadriceps, hamstrings, and gluteal muscle groups are stimulated. The stimulation pattern plays an essential role in segregating the control input across different muscle groups and can vary according to the muscle groups involved and whether a motor is included. Various strategies have been developed to determine the stimulation pattern including: manual determination based on observation, offline numerical optimization, analysis of the person's kinematic relationships, or electromyography (EMG) of able-bodied cyclists.

FES-CYCLING AS A SWITCHED SYSTEM

It is well known that switching between different closed-loop subsystems can destabilize the system, even when those subsystems are exponentially stable (cf., [2],[3]). To induce cycling, FES is applied to different sets of muscles of the left and right legs according to a switching signal dictated by the stimulation pattern, which depends on the crank angular position. Hence, FES-induced cycling is a switched control system with autonomous, state-dependent switching. As illustrated in **Figure 1** there are regions of the crank cycle where it is kinematically inefficient to produce torque (voluntarily or by FES). In these regions, stimulation is not applied, because this can lead to increased muscle fatigue. When muscle groups are activated by a computer-controlled method in the unshaded regions of **Figure 1**, exponential convergence of the cadence tracking error can be achieved [1]; however, when the crank enters the shaded region and no stimulation is applied, the cadence error system can become unstable. Specifically, if the limbs do not have sufficient momentum, when stimulation is removed (and voluntary efforts by individuals are diminished and operating in an inefficient region) the cycle may come to rest in a region where it cannot escape, leading to unbounded cadence tracking error. This problem is exacerbated by the fact that the dynamics of the FES-cycling system are nonlinear, time-varying, and uncertain, so that the system's state trajectories are unknown *a priori* and difficult to predict. With the exception of recent results by the authors (cf. [1], [4, 5, 6]), FES-cycling results have not considered these practical stability issues. Investigating FES-cycling in the light of switched systems theory may yield control strategies that improve FES-cycling performance, thereby increasing the safety and effectiveness of FES-cycling.

In [1], switched systems methods are used to switch between different muscle groups for the right and left legs. Specifically, a stimulation pattern for the gluteal, quadriceps femoris, and hamstrings muscle groups was analytically derived from the kinematics of the cycle-rider system based on the ability of the rider's hip and knee joints to produce a forward torque about the cycle crank. A robust sliding mode control input was then developed based on the derived stimulation pattern with the goal for the rider to pedal (induced by FES) at a desired cadence. A Lyapunov-based analysis was then used to show that the cadence tracking error is exponentially stable in the controlled (unshaded) regions of the crank cycle and could be upper bounded by exponential growth in the uncontrolled (shaded) regions. By developing a ratio between the rate of decrease and rate of increase of the cadence errors in the different regions, sufficient conditions were constructed that indicate how long the crank needs to spend in each region (i.e., dwell-time conditions). The developed conditions are a function of bounds on the uncertain dynamics and the desired cadence. Essentially, from the bounds on the dynamics, the cadence tracking error, and the desired cadence, sufficient conditions can be developed to ensure that there is enough momentum to carry the limbs into the next region of controlled pedaling. The overall error system decays to a residual steady-state error (ultimately bounded stability result).

Since different individuals have a different response to stimulation, experiments were performed in [1] on four able-bodied individuals and one individual with Parkinson's disease. The cycling protocol was reviewed and approved by the University of Florida Institutional Review Board (IRB), and before participating each person was required to meet the inclusion criteria and sign an informed consent. The electrical stimulation control input was delivered to the muscle groups through biphasic, symmetric, rectangular pulses applied to self-adhesive, cutaneous electrodes. The stimulation frequency was fixed at 60 Hz (higher frequencies yield more intense and continuous contractions, but also lead to increased fatigue) and the stimulation intensity was controlled by fixing the pulse amplitude for each muscle group (i.e., between 50-110 mA) and controlling the pulse width according to a sliding mode controller. As indicated in [1], when the healthy normal volunteers were able to look at the desired trajectory error to guide their cycling efforts, they were able to achieve a desired cadence of 50 revolutions per minute (RPM) with an average of -0.14 ± 1.40 RPMs of steady-state error using only volitional effort and no FES contribution. When they were not able to see the desired trajectory and were asked to sit passively while the sliding mode controller coordinated their limbs to produce cycling, the steady-state error was 5.94 ± 1.76 RPMs on average. An example control input across each muscle group of the healthy normal participants is depicted in **Figure 2**.

The subject with Parkinson's disease exhibited mild bilateral motor impairment with evident tremor, where his right side exhibited greater impairment. The impact of his impairment on his cycling performance was that, when his right leg was supposed to pedal, his cadence decreased significantly. This individual was not able to maintain cadence tracking using FES alone (the stimulation intensities to achieve cycling exceeded his tolerance), so comparisons were made with his completely voluntary ability versus his voluntary ability augmented with FES (i.e., FES was used in conjunction with his voluntary effort to compensate for deficiencies in his right side). His average tracking error was 0.43±4.06 RPMs using only voluntary inputs and 0.17±3.11 RPMs when his voluntary inputs were augmented with FES control. **Figure 3** illustrates the differences in stimulation when his right leg was activated versus his left leg (compare to the more symmetric control input for the healthy normal subject).

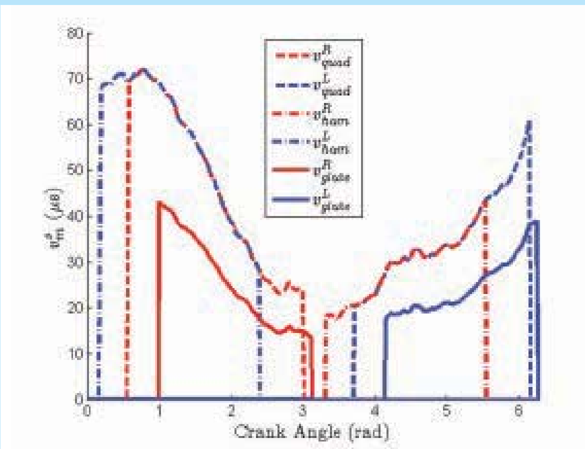


FIGURE 2 Stimulation pulse width for each muscle group for a healthy normal person as a function of the crank cycle.

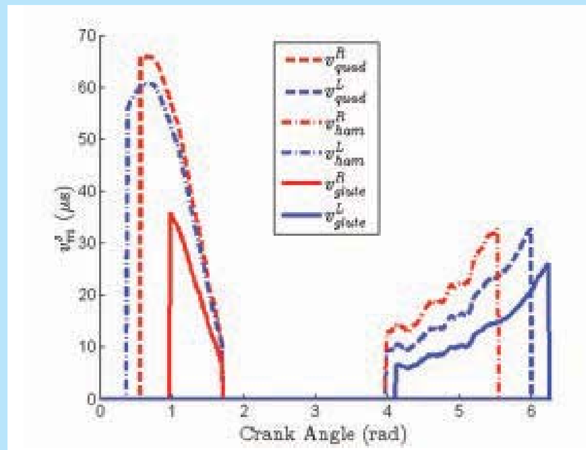


FIGURE 3 Stimulation pulse width for each muscle group as a function of the crank cycle for an individual with decreased strength in the right side due to Parkinson's disease.

MOTORIZED FES-CYCLING AS A SWITCHED SYSTEM

Given the existence of regions in the crank cycle where it is inefficient to produce torque, a motor can be included as another torque source. See the Sidebar "Motorized Cycling Testbed Construction" for further details on an example cycle testbed. From a review of research results and commercial products, the use of a motor to augment FES cycling is common, but when the motor is activated and in what capacity varies significantly. In [4], the motor input was only used in the regions where the torque production was inefficient and FES was turned off (i.e., the shaded regions in **Figure 1**). From a rehabilitation perspective, only using the motor in the inefficient regions maximizes the effort required by the person (in contrast to other designs where the motor continuously provides assistance) and helps to reduce fatigue since a person's muscles are only activated when it is kinematically efficient to do so, which can vary depending on a person's physiology and ability to produce torque. From a control systems perspective, the advantage of using a motor is that it eliminates the uncontrolled regions, simplifying control design and analysis strategies. That is, compared to results such as [1], switching with a motor in the loop only involves switching between stable subsystems. FES control of the muscles yields cadence tracking in torque efficient regions while the motor yields cadence tracking when it is inefficient for the limbs to produce torque. A sliding mode controller is developed in [4] for the muscle control inputs and the motor. Since each closed-loop error system is stable, a single Lyapunov function can be established to show global exponential tracking for the overall switched system, without the need to develop sufficient dwell-time conditions. Experiments were performed on five healthy normal individuals in [4], where they were not informed of the desired trajectory and were asked to relax and let the FES and motor controller manage the cycling cadence. In these experiments, only the hamstrings and quadriceps were stimulated. The average error across all five subjects for

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Matthew Bellman has been a member of the Nonlinear Controls and Robotics Group since May 2009, and has since received both his bachelor's and master's degrees, magna cum laude, in mechanical engineering with a minor in biomechanics from the University of Florida. Matthew recently completed his doctoral degree in mechanical engineering as a National Defense Science and Engineering (NDSEG) Fellow, with a focus on the theoretical development of robust, adaptive control systems for applications involving functional electrical stimulation, specifically those involving rehabilitation and mobility of the lower extremities. His work has been recognized by the 2015 American Automatic Control Council (AACC) O. Hugo Schuck (Best Paper) Award

Prof. Warren Dixon received his Ph.D. in 2000 in the Department of Electrical and Computer Engineering from Clemson University. He was selected as an Eugene P. Wigner Fellow at Oak Ridge National Laboratory (ORNL). In 2004, he joined the University of Florida in the Mechanical and Aerospace Engineering Department. His main research interest has been the development and application of Lyapunov-based control techniques for uncertain nonlinear systems. He has published 3 books, an edited collection, 12 chapters, and over 120 journal and 220 conference papers. His work has been recognized by the 2015 & 2009 American Automatic Control Council (AACC) O. Hugo Schuck (Best Paper) Award, the 2013 Fred Ellersick Award for Best Overall MILCOM Paper, a 2012-2013 University of Florida College of Engineering Doctoral Dissertation Mentoring Award, the 2011 American Society of Mechanical Engineers (ASME) Dynamics Systems and Control Division Outstanding Young Investigator Award, the 2006 IEEE Robotics and Automation Society (RAS) Early Academic Career Award, an NSF CAREER Award (2006-2011), the 2004 Department of Energy Outstanding Mentor Award, and the 2001 ORNL Early Career Award for Engineering Achievement. He is an ASME and IEEE Fellow, an IEEE Control Systems Society (CSS) Distinguished Lecturer, and served as the Director of Operations for the Executive Committee of the IEEE CSS Board of Governors (2012-2015). He currently serves as a member of the U.S. Air Force Science Advisory Board. He is currently or was formerly an associate editor for *ASME Journal of Journal of Dynamic Systems, Measurement and Control, Automatica, IEEE Control Systems Magazine, IEEE Transactions on Systems Man and Cybernetics: Part B Cybernetics, and the International Journal of Robust and Nonlinear Control.*

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a desired cadence of 50 RPM was 0.00±2.91 RPM. The stimulation/motor control input for one cycle by an example individual is depicted in **Figure 4**.

CONCLUSIONS AND ONGOING WORK

FES plays an important role in the rehabilitation of individuals with neurological disorders that exhibit muscle dysfunction. The potential impact to society and the daily lives of individuals with certain neurological disorders provides significant motivation to examine the challenges associated with FES-induced activities. In particular, FES-induced cycling is a common activity-based rehabilitation therapy because it is a safe, repetitive, and low impact exercise. However, as illustrated by the aforementioned studies, there exist significant challenges to the development of FES controllers for the uncertain, switched, nonlinear dynamic system.

While some success has been achieved by using various off-the-shelf control solutions, significant promise exists for new developments to emerge from the control and robotics communities, where constructive

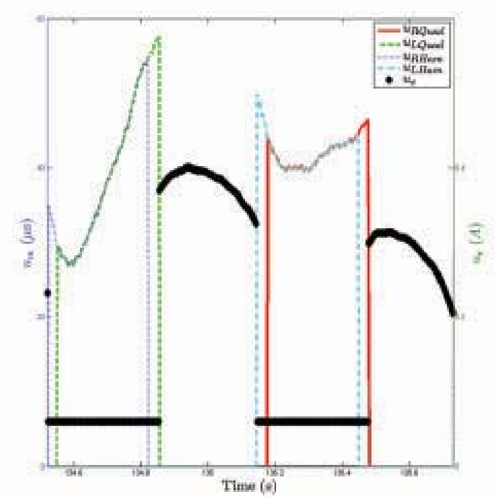

FIGURE 4 **Stimulation pulse width (denoted by u_m in microseconds) and motor control (denoted by u_e in amps) inputs for the quadriceps and hamstring muscle groups and an electric motor for an example healthy normal individual.**

methods could be developed and analyzed for the problems with FES-induced activities. In particular, the control systems and robotics communities have the potential to make significant inroads in FES-cycling, where relatively few constructive closed-loop controllers have been published. To date, only robust control tools have been used to develop a stability analysis for the switched system. However, motivation exists to develop and analyze adaptive and learning controllers which may exhibit lower frequency content and/or lower magnitude control intensities. Such developments may lead to reduced muscle fatigue, thereby extending the rehabilitative treatment, and to better measures of therapeutic outcomes by means of system identification strategies. When switching between stable and unstable regions (i.e., without a motor in the loop), significant challenges remain in developing sufficient dwell-time conditions to ensure stability for adaptive switched systems. Specifically, since adaptive systems typically yield asymptotic convergence, the development of dwell-time conditions is an open challenge. The inclusion of a motor enables switching between stable systems and eliminates the need for the development of sufficient dwell-time conditions. Hence, the development of adaptive switched controllers for motorized FES-cycling systems may have a closer horizon. The inclusion of a motor also expands the possible control objectives that can be pursued. For example, physical therapists would like to prescribe both a desired power output and cadence for individuals participating in cycling therapies. Based on results such as [7,8], the motor could be tasked with maintaining cadence control, allowing the FES inputs to yield desired torques. Such development is still in the early stages, and various adaptive and learning tools can potentially be developed to advance such goals. ■

FIGURE 5 **Stationary motorized FES cycle testbed.**

MOTORIZED CYCLING TESTBED CONSTRUCTION

The latest motorized FES cycle used at the University of Florida Nonlinear Control and Robotics Laboratory is a modified, commercially available recumbent tricycle (TerraTrike Rover) depicted in Figure 5. A 250 Watt, brushed, 24 VDC electric motor was mounted to the frame and coupled to the drive chain. Orthotic boots incorporated with custom pedals are used to fix the rider's feet to the pedals, prevent dorsiflexion and plantarflexion of the ankles and maintain sagittal alignment of the lower legs. An optical encoder is coupled to the cycle crank via spur gears to measure the crank position. Current control of the cycle's motor was enabled by a linear amplifier interfacing with data acquisition hardware (Quanser Q8-USB), which also measured the encoder signal. To ensure safe operation, an emergency stop is included and, when people are seated on the tricycle, the tricycle's seat position is adjusted for each subject's comfort while ensuring that full extension of the knees is not possible (to prevent hyperextension). Electric stimulation is provided by a commercial, current-controlled, eight-channel stimulator (RehaStim, Hasomed) interfaced with a personal computer and cutaneous electrodes (Axelgaard Manufacturing Co. Ltd.). One pedal is attached to a cycling power meter (SRM) that wirelessly transmits the torque produced at the crank for experiments that involve power tracking control objectives.

CAREBOTS: PROLONGED ELDERLY INDEPENDENCE USING SMALL MOBILE ROBOTS

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A recent study from the U.S. Department of Housing and Urban Development showed that most seniors would prefer to age in place, and a survey from the AARP concluded that nearly 90% of citizens 65+ wished to remain in their homes for as long as they can [1]. However, prolonging independence is a challenging task for today's healthcare system due to its increased costs and technical feasibility. Although many advances in mobile technology, robotics, and wearable devices have been made, family members and professional caregivers are still the main options older adults have to further extend their capability of aging safely and comfortably at home. Based on the U.S. Census Bureau, the population of U.S. adults who are 65 and older is projected to be twice as large in 2030 as it was in 2000, increasing from 35 million to 71.5 million and representing nearly 20 percent of the total U.S. population [2]. The current caregiving model will increase health care costs to unrealistic standards and cause disruptive changes to how individuals and families manage late-in-life decisions.

Although embedded with smart features and innovations, appliances such as washing machines, microwaves, vacuum cleaners and other household machines are still rigid when it comes to multiple functionalities. Technology that is flexible enough to help us at home, by carrying out multiple distinctive tasks, has been a driving motivation for the robotics community. Efforts with bio-inspired ground robots [3] have shown how complicated and large robots can become and how challenging it can be to replace caregivers with such cumbersome robots. Furthermore, finding home assistive robots that have elderly independence as the core development goal is difficult. To engineer an acceptable and useful technology, a framework must prioritize flexibility of operation and usability as the foundation for safe and trusted interaction; user acceptance lies almost solely within the purview of the elderly.

Our human-robot system allows the elderly to cooperate with small flying robots through an appropriate interface. This team of small robots is more affordable, more agile, smaller, and can reach higher floors and tighter spaces. We use experimental data to study older adults' perceptions of non-humanoid robots to design a platform that is acceptable and does not interfere with their comfort of living at home.

ASPIRE
Automation Supporting Prolonged Independent Residence for the Elderly

In order to achieve this flexible and adaptable framework, the project ASPIRE is redesigning the way small aerial vehicles (UAVs) interact with humans. The mechanical simplicity of multi-rotors makes them an affordable platform that has the potential of performing precision flight maneuvers with onboard grasping solutions and sensing hardware, which can be employed in activities that are not attainable by traditional humanoid or ground vehicles, e.g. reaching up high to grab objects. A human-centered design of a flying robotic platform is being developed to achieve the goal of providing caregiving with multi-rotor UAVs.

ASPIRE provides a platform where High-Level Controllers (HLC) can be designed in order to provide a layer of abstraction between the high-level task requests, the perceptual needs of the users, and the physical demands of the robotic platforms, shown in **Figure 1**.

With a robust framework that has the capability to account for human perception and comfort level, we can provide perceived safety for older adults, and further, add expressivity that facilitates communication and interaction

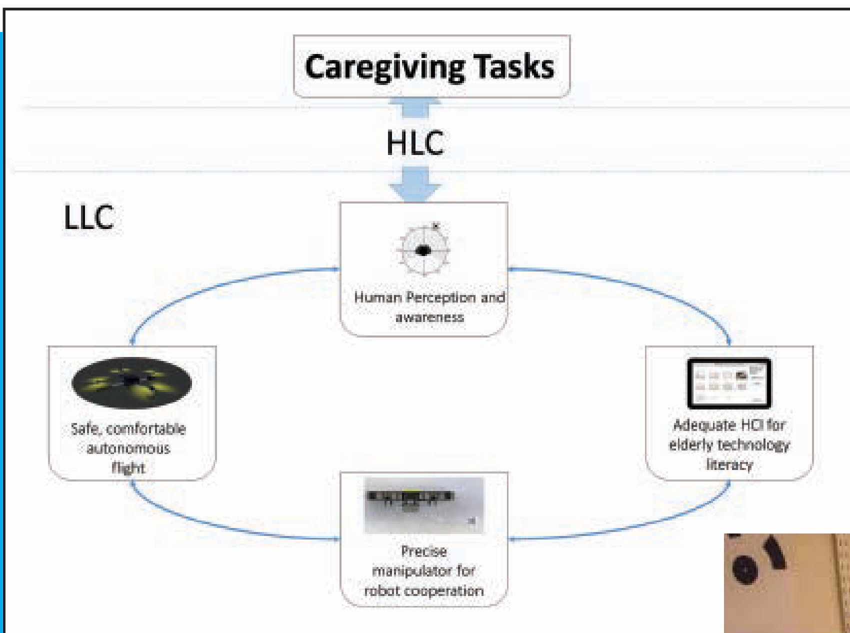


FIGURE 1 ASPIRE HLC and LLC integration.

FIGURE 2 VR simulation of UAV flight during biometric data acquisition.

FIGURE S1 Human observer and UAV interact in VR.

WHY VIRTUAL REALITY?

Virtual Reality (VR) is a desirable tool because it offers a safe and flexible environment in which the investigator has extremely granular control over the user experience. For example, aspects of the robot's physical appearance (e.g. shape, ergonomics, or durability), behavior (e.g. movement, manipulation, or sensing), and environmental context (e.g. low light, noise, or verticality), all constrain a robot's flight path and can be manipulated in isolation to reveal their unique effect on human observers. The human observer, however, also brings with them personal experiences that can influence the perception of a robot's agency and therefore its trustworthiness, safety, and so on.

between the user and the robotic team. To achieve these demanding levels of comfort, predictable and safe navigation must be guaranteed by the underlying Low-Level Controller (LLC), which is fundamental for indoor locomotion of any robotic form. Embedding human perception into the LLC and HLC is done by collecting experimental data from human subjects to understand how humans behave in the presence of these UAVs.

HUMAN PERCEPTION AND PERFORMANCE

The ASPIRE project addresses two fundamental issues that arise when deploying robotic systems to real-life human populated environments: (1) How do we characterize human behavior in the presence of co-located mobile robots? (2) How do we design and control mobile robots to maximize comfort and perceived safety for co-located others? Using current generation VR devices, in combination with physiological recordings, self-report data, and behavioral measures, we are able to generate a detailed model of human behavior in these situations. For details see "Why Virtual Reality?"

For example, our ongoing research with older adults and college-aged students explores the role of uncertainty and perceived safety in non-cooperative multi-rotor UAV interactions. In one version of this experiment, participants wear a VR head-mounted display (HMD) and enter a high fidelity simulation of an urban scene (see **Figure 2**.). During the simulation they experience several unanticipated UAV flybys, the nature of which is manipulated experimentally across subjects (e.g., distance to user, speed, or loudness). Biometric data is sampled continuously throughout the simulation, including galvanic skin response (GSR), photoplethysmography (PPG), and head rotation (e.g. angular (rotational) acceleration (1 rad/s^2) and linear acceleration (1 m/s^2), as a function of time-to-collision. Other demographic information related to athletic activity, UAV experience, and video game playing history, is collected offline and included in subsequent analysis. It is imperative to consider these types of continuous, indirect measures in order to acquire an unmitigated response from the human observer.

While it would be possible to simply ask participants to indicate their attitudes about UAV interaction, these types of deliberative questions can often result in an "I don't know" or "I'm not sure" response; this is often because the participant does not want to report the answer, does not understand the question, or legitimately does not know. Indirect measures, like those mentioned above, circumvent these types of self-report issues. For example, in response to the UAV's presence, increased arousal can lead to the sweat glands becoming more active, increasing moisture content on the surface of the skin, and allowing electrical current to pass more easily. This effect is known as skin conductance and is often cited as a measure of arousal or state anxiety [4]. Similarly, using an optical pulse sensor placed near soft tissue (e.g. fingertip or earlobe) a PPG signal can be acquired and processed to determine the heart rate, which is known to increase with arousal [5]. Together these two signals help provide a comprehensive description of a participant's emotional response during a given UAV interaction. While this methodology provides an indirect assessment of an individual's automatic response to an unanticipated drone interaction, it is equally important to

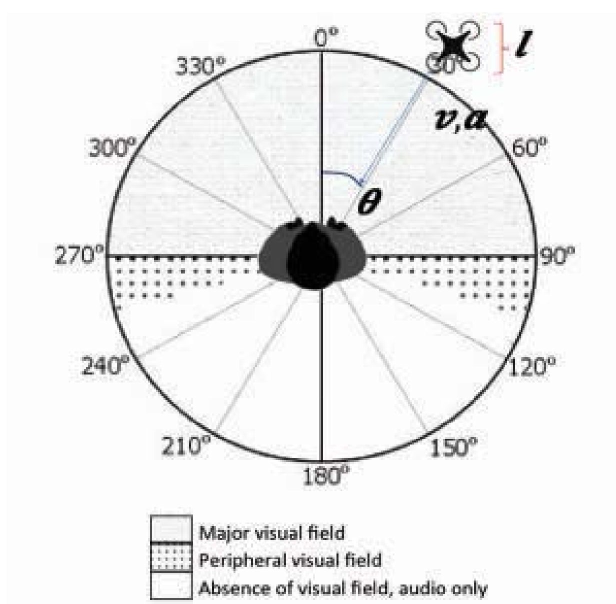


FIGURE 3 Example of different physical parameters during experiment.

THE ROBOTIC PLATFORM

Design of a small robot suitable for indoor flight capable of minimizing disruption and discomfort is done by incorporating the findings from the experimental research with humans. Flying multi-rotors pose the hardest design constraints because the desired functionalities (such as flight endurance, payload capabilities and precision manipulation) are contrary to the characteristics needed for human acceptance (compact, quiet and lightweight).

To achieve the highest possible thrust-to-weight ratio while also satisfying payload constraints with commercially available parts, the multi-rotor is chosen to be 208 mm in diameter with desirable maximum total thrust of over 1.6 kg.

A two-degree-of-freedom serial manipulator was designed with an open truss structure in order to further decrease weight. Although the flight controllers are capable of preventing collisions, a protective enclosure is added on the outer part of the robot, see Fig. S2. This fully protective enclosure augments the safety of the system, but most importantly, communicates a message of safety to the user.

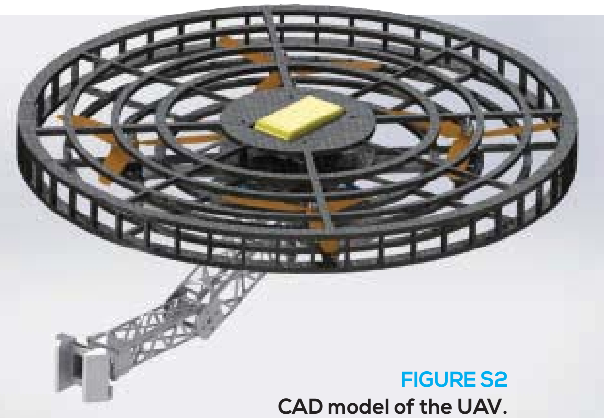


FIGURE S2
CAD model of the UAV.

acquire direct measures of behavior and to do so for circumstances in which a UAV interaction is not only expected, but also expected to be cooperative.

To this end, another series of experiments focuses on assessing boundaries of perceived safety by measuring the proximal distance in which users feel comfortable interacting with a co-located UAV. These experiments recruit both college-aged students and older adults, but extend the findings of our previous research by enabling users to locomote freely in a small area and provide commands to the UAV using a hand-tracked controller. This additional layer of complexity helps to better simulate a real-world scenario in which an older adult must cooperate with a UAV in performing a given task. By collapsing across responses from many trials under different conditions, we can generate a boundary of an interaction space within which a human observer feels comfortable interacting with the UAV. Because we expect carebots to be operating in assisted living communities or elderly care facilities, we can use this data to design parameters for the LLC, such as proximity bounds, velocity profiles, and obstacle avoidance thresholds (see **Figure 3**.).

CHOREOGRAPHY OF EXPRESSIVE ROBOT TRAJECTORIES

The user's perceived safety of the robot will also be based on their ability to determine the state of the current robot team. This requires communication via expressive robotic movement. For example, if the user requests a task to be accomplished with urgency, they will expect a more aggressive action from the system and thereby the parameters of perceived safety will change. The HLC will combine user requests with expressive actions and communicate new appropriate parameters to the LLC. The team is using Laban/Bartenieff Movement Studies (LBMS) to choreograph these expressive pathways. This system of movement analysis and notation provides a taxonomy with which to describe the robot motion. Principles of body organization and movement quality, mapped to a quantitative measure of platform expressivity and task complexity, will guide the design of the HLC and the commands the user interface supports [6].

A HUMAN-CENTERED APPROACH

It is important that we not only design our system to be acceptable to users, but that it helps them in their goal of aging in place. We are motivated by recent research on factors most important in driving elders out of independent living. In [7], literature searches and focus groups found that the factors most threatening to independence are related to problems with mobility, self-care, and social isolation. Thus, our goal is to mitigate some of those underlying factors through useful applications. Using UAVs to manipulate objects in the home is an example of how we can assist older adults when they are limited by mobility or reach. If they have difficulty with medication adherence, the correct medicine can be delivered directly to them, along with water or food. It is also important to use such technology to forestall further decreases in the user's own capabilities – the robots could be utilized as personal dance partners to help keep users physically and mentally fit and socially fulfilled. The embodied cognition of the UAVs make them suitable and compelling to users as partners in their everyday lives, as opposed to an app on a phone – they can work together towards the goal of extending the user's sphere of functionality.

Our current interface concept, in the form of a tablet computer and shown in **Figure 4**, takes into account much literature on designing interfaces according to the preferences and abilities of older adults, especially due to physical and cognitive declinations. For example, we eliminate anything that is not crucial, simplify navigation, and highlight important information due to diminished working memory and attention [8].

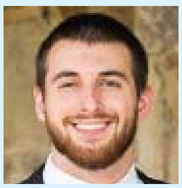
SAFE AUTONOMOUS FLIGHT

Safe indoor navigation for UAVs is a multi-pronged problem consisting of trajectory generation, collision avoidance, path following and state estimation while also acknowledging the safety concerns of humans in proximity.

To incorporate a human-centered approach to the navigation problem we propose an optimal control formulation **Equation (1)**, which includes the perceived safety of humans as a constraint to generate trajectories and colli-

ABOUT THE AUTHORS

Thiago Marinho is a PhD student in Mechanical Engineering at the University of Illinois at Urbana-Champaign. He received his MS degree in Control and Automation Engineering from the Ecole Centrale de Lille, France. Current interests include control theory, state estimation and mobile robotics.



Christopher Widdowson is a PhD student in the Department of Psychology at the University of Illinois at Urbana-Champaign. He received an MS degree in experimental psychology from the University of Texas at San Antonio in 2014. Interests include virtual reality, 3D computer graphics, experimental design, and spatial cognition.

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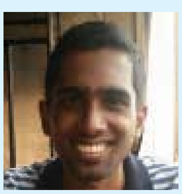

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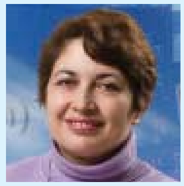
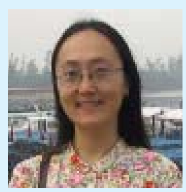
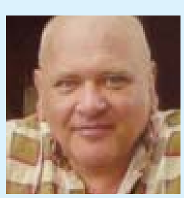


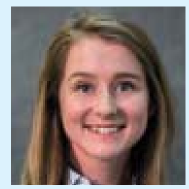
Naira Hovakimyan is currently the W. Grafton and Lillian B. Wilkins Professor of Mechanical Science and Engineering at the University of Illinois at Urbana-Champaign. She received her M.S. degree in Theoretical Mechanics and Applied Mathematics in 1988 from Yerevan State University in Armenia and her Ph.D. in Physics and Mathematics in 1992, from the Institute of Applied Mathematics of Russian Academy of Sciences. Research interests are in the theory of robust adaptive control and estimation, control in the presence of limited information, networks of autonomous systems, game theory and applications of those in safety-critical systems.



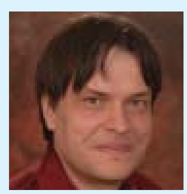
Ranxiao Frances Wang received her Ph.D from Massachusetts Institute of Technology in 1999 in Computational Cognitive Sciences and is currently a professor in the Department of Psychology at the University of Illinois. Dr. Wang's research focuses on visual and spatial cognition, including how people encode and process spatial information during navigation; how humans perceive optic flow and make judgments about their locomotion; how the visual system temporally separates and integrates the continuous stream of optical stimulation to coherent percepts; how people recognize objects and scenes, and human spatial representations of higher-dimensional objects and space.



Alex Kirlik received his BS, MS and Ph.D in Industrial & Systems Engineering from Ohio State University and is currently Professor of Computer Science and Member of the Beckman Institute at the University of Illinois at Urbana-Champaign, where he served as Head of Human Factors for 5 years. His current research focuses on techniques for facilitating human-automation interaction. He has published more than 100 peer-reviewed research articles. He is editor of *Adaptive Perspectives on Human-Technology Interaction* (OUP, 2006)*, editor of Human-Tech: Ethical and Scientific Foundations* (OUP, 2010)*, and co-editor of The Oxford Handbook of Cognitive Engineering* (2013).



Amy LaViers is an assistant professor in Mechanical Science and Engineering at the University of Illinois at Urbana-Champaign and director of the Robotics, Automation, and Dance (RAD) Lab. She will receive a CMA from the Laban/Bartenieff Institute in 2016, and received a PhD from Georgia Tech in 2013, an MS from Georgia Tech in 2010, and a BSE from Princeton in 2009. Her research interests are embodied movement theory and style in supervisory control systems for expressive robots. She is a 2015 DARPA Young Faculty Award recipient.



Dušan Stipanović received his B.S.E.E. degree from the University of Belgrade in 1994, and the M.S.E.E. and Ph.D. degrees from Santa Clara University in 1996 and 2000, respectively. Dr. Stipanović had been a Research Associate in the Department of Aeronautics and Astronautics at Stanford University (2001-2004). In 2004 he joined UIUC where he is now Associate Professor in the ISE Department and CSL. His research interests include decentralized control and estimation, and dynamic games. Dr. Stipanović served as an Associate Editor for IEEE TCAS I and II. Currently he is an Associate Editor for JOTA.

FIGURE 4
Tablet interface concepts for help finding, delivering, and viewing objects.

sion avoidance methods to navigate around obstacles in the environment. Since quad-rotor dynamics are differentially flat, the optimization can be devised in the output space, allowing us to easily add constraints such as velocity, acceleration, distance to obstacles, and human perceived safety directly to the problem formulation. The inference derived from the psychological experiments in VR will provide an expedited method to weigh the importance of these quantities against perceived safety and design constraints for the optimal control problem accordingly.

Safe optimal trajectories for the UAVs can be generated by minimizing the following cost functional:

$$J = \Phi\,(x\,(t_0),\, t_0,\, x\,(t_f),\, t_f) + \int_{t_0}^{t_f} E\,(x\,(t),\, u\,(t),\, t)\; dt \qquad \textbf{(1)}$$

subject to

multi-rotor dynamics	$\dot{x}\,(t) = f\,(x\,(t),\, u\,(t),\, t)$,
boundary conditions	$\Phi\,(x\,(t_0),\, t_0,\, x\,(t_f),\, t_f) = 0$,
obstacle avoidance	$B\,(x\,(t),\, u\,(t),\, t) \le 0$,
perceived safety constraints	$P\,(x\,(t),\, u\,(t),\, t) \le 0$,

where $E\,(x\,(t),\, u\,(t),\, t)$ is the state, input and/or time dependent running cost.

In order to provide a flight that does not adversely affect perceived safety, we must precisely follow the trajectory solved by the optimal control problem. Large deviations from the optimal solutions will disrupt the human's level of comfort. We use nested feedback loops in order to guarantee tight performance bounds. Rate and attitude controllers provide stable flight and can also achieve behavior specific goals, e.g., "friendly" and less aggressive movements, bounds on velocity and acceleration. To fly UAVs through unstructured and cluttered environments in households, we use a trajectory-tracking controller, which guarantees precise locomotion in space. To ensure a predictable flight and guarantee minimal deviation from the designed level of comfort, we use a robust and adaptive control for the inner-loop controller design. The L1 adaptive control architecture is designed for such safety critical systems and provides the required robustness and performance [9].

CONCLUSION AND FUTURE WORK

This paper demonstrates a multidisciplinary approach that proposes to augment future caregiving by prolonging independence for older adults. The proposed framework relies on an iterative process of LLC design through experimental data collected from psychological trials. We also present an intuitive tablet-based interface design for effective communication with the carebots.

Future work includes the exploration of multiple carebots to cooperatively assist in caregiving tasks based on our human-centered design approach. We are also investigating more lightweight and natural voice- and gesture-based interaction methods between humans and the carebots. ■

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2016 ASME Dynamic Systems and Control Conference

Minneapolis, MN, October 12-14, 2016

THE NINTH ASME DYNAMIC SYSTEMS AND CONTROL CONFERENCE (DSCC) will be held in Minneapolis, Minnesota, October 12-14, 2016.

KIM STELSON (University of Minnesota) and **JIONG TANG** (University of Connecticut) will serve as General Chair and Program Chair, respectively.

The DSC Conference, organized and led by the members of the **ASME DSC Division**, provides a focused and intimate setting for dissemination and discussion of the state of the art in the broad area of dynamic systems and control from theory to industrial applications and innovations in education.

In addition to regular sessions, the conference program will also include **contributed sessions, invited sessions, tutorial sessions, special sessions, workshops, and exhibits.**

The 2016 DSCC will be preceded by the **FLUID POWER INNOVATION AND RESEARCH CONFERENCE (FPIRC)** at the same location, October 10-12, 2016, which offers an expanded research program and more networking opportunities.

Edited by Kim Stelson and Rifat Sipahi

For details on the conference schedule, please visit ASME Conferences at https://www.asme.org/events/dscc

Photo courtesy of Meet Minneapolis
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2017 AMERICAN CONTROL CONFERENCE

Seattle, WA, May 24–26, 2017

The 2017 AMERICAN CONTROL CONFERENCE will be held Wednesday through Friday, May 24-26, at the Sheraton Seattle Hotel in the heart of Seattle, Washington – the most visited city in the Pacific Northwest. The conference venue is near nightlife, restaurants, shopping, and entertainment, just a walk to all of Seattle's known sights such as the Seattle Waterfront, Pike Place Market, Space Needle, Seattle Aquarium, and the Washington State Ferries.

The ACC is the annual conference of the American Automatic Control Council (AACC, the U.S. national member organization of the International Federation for Automatic Control (IFAC)). National and international society co-sponsors of ACC include American Institute of Aeronautics and Astronautics (AIAA), American Institute of Chemical Engineers (AIChE), Applied Probability Society (APS), American Society of Civil Engineering (ASCE), American Society of Mechanical Engineers (ASME), IEEE Control Systems Society (IEEE-CSS), International Society of Automation (ISA), Society for Modeling & Simulation International (SCS), and Society for Industrial & Applied Mathematics (SIAM).

The 2017 ACC technical program will comprise several types of presentations in regular and invited sessions, tutorial sessions, and special sessions along with workshops and exhibits. Submissions are encouraged in all areas of the theory and practice of automatic control.

Draft Manuscripts are due September 19, 2016.

Details can be found on the conference web site at http://acc2017.a2c2.org

2017 Seattle ACC

Global Gas Turbine News

Volume 55, No. 3 • September 2016

In This Issue

ASME INTERNATIONAL GAS TURBINE INSTITUTE

Seoul Welcomes ASME Turbo Expo to Asia for First Time in 2016.

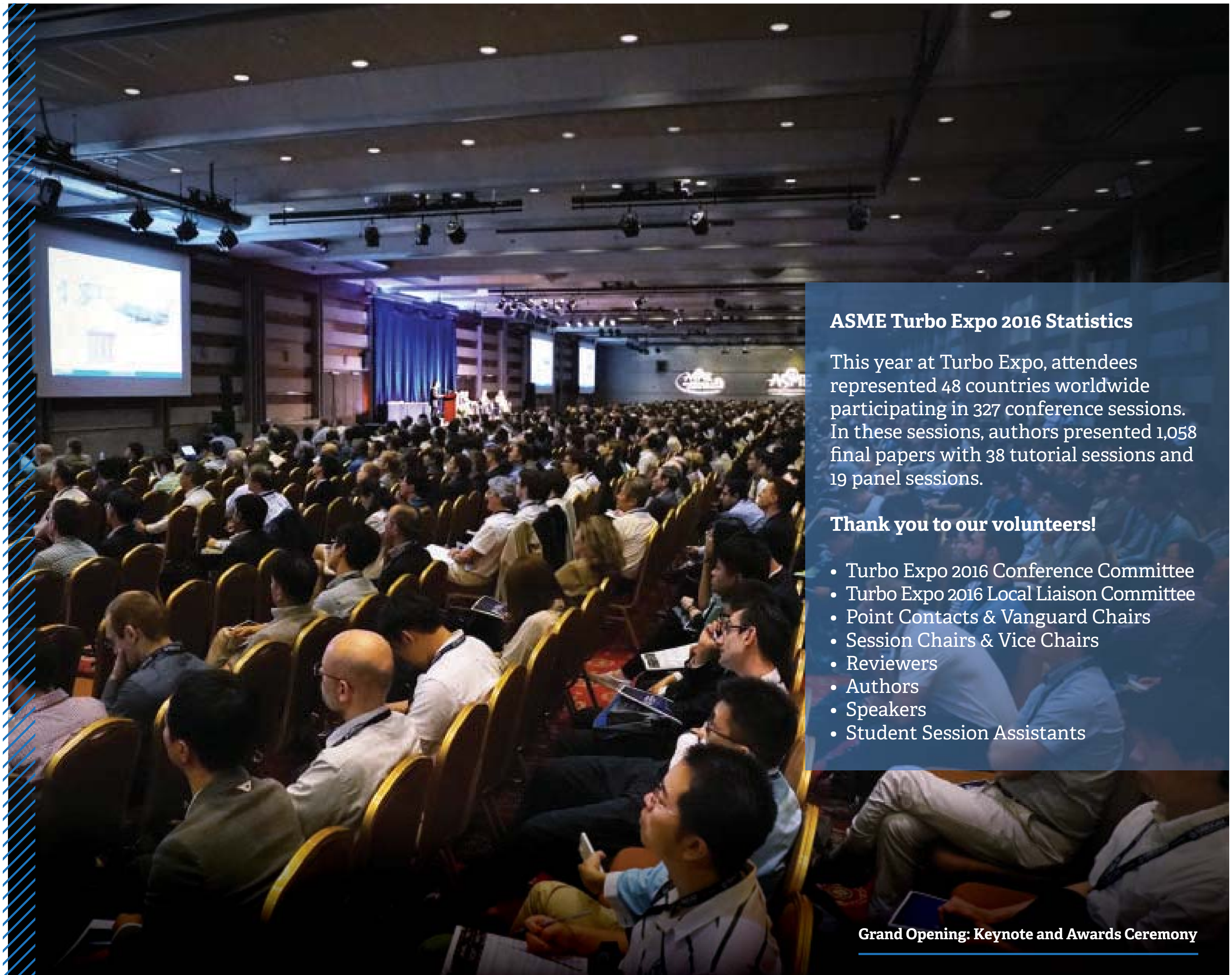
ASME Turbo Expo 2016 in Seoul, South Korea maintained its reputation as the world's premier gathering of over 2600 turbomachinery professionals. Throughout the week, delegates shared practical experiences, knowledge and ideas on the latest turbine technology trends and challenges. Many expressed their appreciation for the conference, noting that it was an amazing experience and particularly in receiving valuable feedback on research from experts in the field. Being in a different part of the world, delegates from 48 countries participated. Changing the format of the keynote from a lecture session to a panel session introduced a fresh dynamic into this time. The audience actively submitted questions while the moderators collected and asked the panelists for their insight. Bringing their expertise and experience, they made the new format a worthwhile part of the conference. Led by Bill Newsom of Mitsubishi Hitachi Power Systems Americas, Inc., and Tim Lieuwen of Georgia Tech, the opening session featured an exceptional keynote focused on "Energy and Propulsion in the Information Age", with panelists Eric Gebhardt, Daniela Gentile, and Alan Epstein, followed by the annual awards program of prestigious ASME and IGTI awards.

The new plenary panel sessions were well attended with great audience participation. Led by James Maughan and Klaus Brun the Tuesday morning plenary session explored opportunities and threats with open discussion on future outlooks for asset monitoring. Panelists Maria Sferruzza, Eisaku Ito, and Paul Stein did a great job presenting and responding. The Wednesday morning session led by Karen Thole and Rich Dennis explored the new industrial manufacturing renaissance and what would be coming next, with panelists Vinod Philip and Akimasa Muyama. The Technical Conference offered five days of over 1,000 technical paper presentations, including a special honorary lecture by 2016 Aircraft Engine Technology Award winner, Dr. Je-Chin Han from Texas A&M University.

After the technical sessions finished for the day it was nice to wind down with the evening events throughout the week. On Monday evening over 1,500 came out for the welcome reception featuring a Soriwul band supported by the Local Liaison Committee. On Tuesday the women working in turbomachinery attended a networking event featuring talks from Patricia Cargill of GE and Anne Jesuthasan of Siemens, sponsors of the event. On Wednesday many students and early career engineers got a chance to get acquainted with one another at the mixer sponsored by Doosan. During the three-day exposition, delegates met with representatives from premier companies supplying quality turbomachinery products and services. Special recognition during the Closing Ceremony went to ANSYS and Vectoflow GmbH, as exhibition visitors voted their displays the best. Student Posters were presented on Tuesday and Wednesday afternoons in the exhibition hall with first place being awarded to Matthias Kunick from the Zittau/Goerlitz University of Applied Sciences, second place to Joshua Keep from the University of Queensland, and the people's choice awarded to Amir Ibrahim from the University of Oxford.

If turbomachinery is part of your professional life, you cannot afford to miss the annual ASME Turbo Expo! To plan for 2017, see page 82 of this issue and keep informed throughout the year by visiting ASME Turbo Expo online at https://www.asme.org/events/turbo-expo.

See the award winners on page 78



ASME Turbo Expo 2016 Statistics

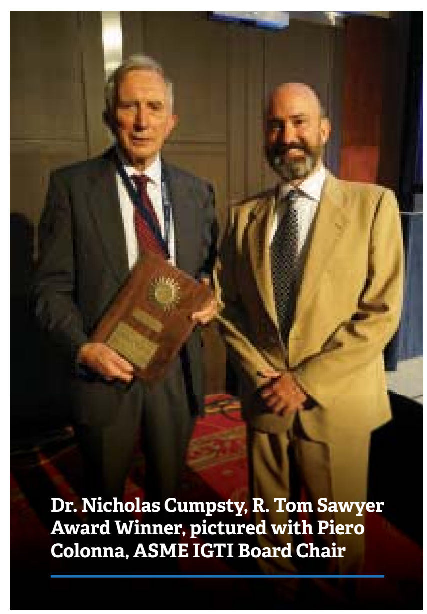
This year at Turbo Expo, attendees represented 48 countries worldwide participating in 327 conference sessions. In these sessions, authors presented 1,058 final papers with 38 tutorial sessions and 19 panel sessions.

Thank you to our volunteers!

- Turbo Expo 2016 Conference Committee
- Turbo Expo 2016 Local Liaison Committee
- Point Contacts & Vanguard Chairs
- Session Chairs & Vice Chairs
- Reviewers
- Authors
- Speakers
- Student Session Assistants

Grand Opening: Keynote and Awards Ceremony

Grand Opening: Panel Discussion with Audience Q&A



Dr. Nicholas Cumpsty, R. Tom Sawyer Award Winner, pictured with Piero Colonna, ASME IGTI Board Chair

ASME 2016 Turbo Expo Highlights continued on the next page...

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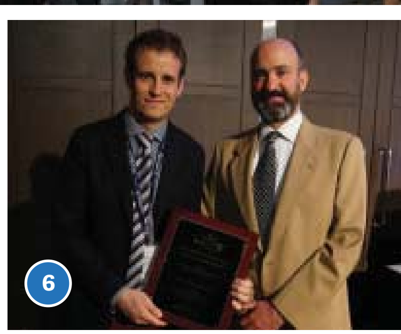
ASME 2016
TURBO EXPO



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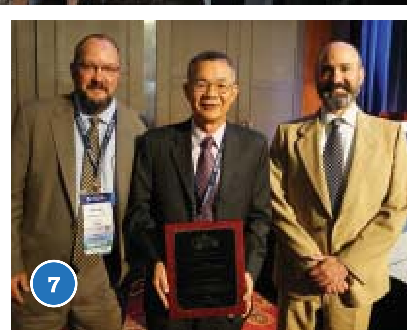

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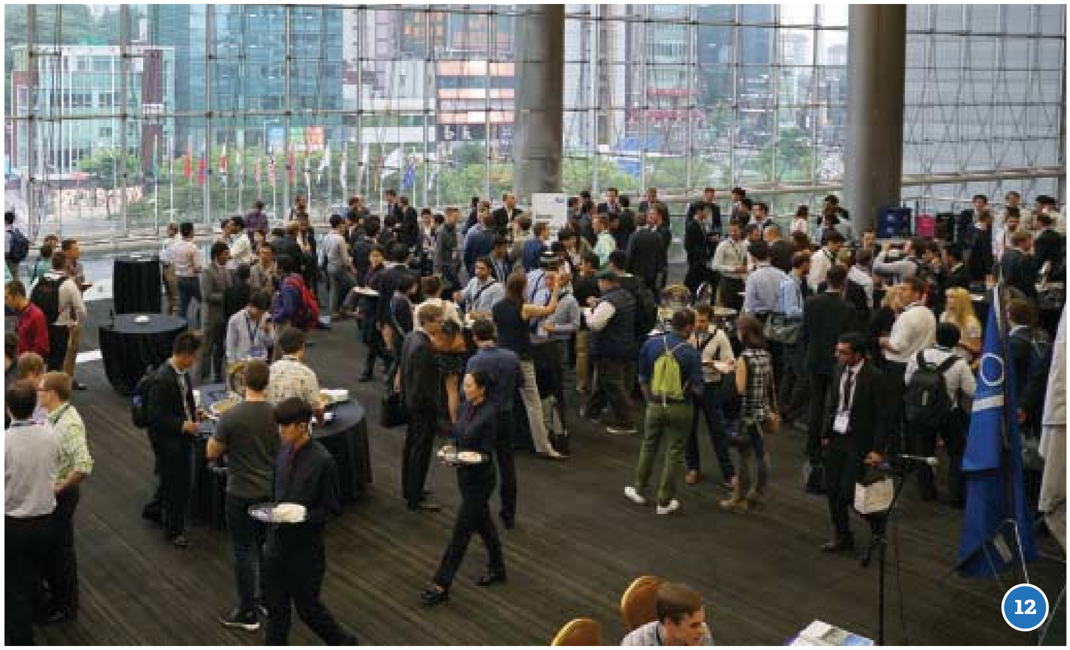

ASME 2016 Turbo Expo Conference Highlights

1. Tuesday plenary
2. Wednesday plenary
3. Congratulations to the 2016 Turbo Expo Student Advisory Committee Travel Award Winners.
4. Congratulations to the 2016 Young Engineer Turbo Expo Participation Award Winners.
5. Dr. Robert Grewe and Dr. Robert Miller, 2014 ASME Gas Turbine Award Winners, pictured with Piero Colonna, ASME IGTI Board Chair
6. Dr. Carl Sangan, Dilip R. Ballal Early Career Award Winner, with Piero Colonna, ASME IGTI Board Chair
7. Dr. Je-Chin Han, Aircraft Engine Technology Award Winner, pictured with Andrew Nix, Aircraft Engine Committee Chair, and Piero Colonna, ASME IGTI Board Chair
8. Dr. Klaus Brun, Industrial Gas Turbine Technology Award Winner, pictured with Piero Colonna, ASME IGTI Board Chair
9. Patricia Cargill of GE speaking at the Women in Turbomachinery Networking Event
10. Congratulations to ANSYS for being selected as the People's Choice for Best Large Booth.
11. Congratulations to Vectoflow for being selected as the People's Choice for Best Small Booth.
12. The student mixer was well attended by over 700 young turbomachinery professionals. The students had an opportunity to network with their peers in a relaxed atmosphere with delicious food and drinks.
13. Student Mixer Sponsored by Doosan
14. Women in Turbomachinery Networking Event sponsored by GE and Siemens

"As the Turbine Turns...."

#27 September 2016

Lee S. Langston Professor Emeritus
Mechanical Engineering
University of Connecticut

Some Details of Jet Engine Thrust

Typically, jet airline passengers do not pause to think about it, but part of their ticket purchase is for thrust, the thrust required to fly them to their destination. Jet engine thrust is the force produced by an engine that acts on its aircraft mounts, to pull their plane forward in flight. It is readily measured by load cells when an engine is run in a test stand.

As engineers, some of us have probably been asked by non-engineers to explain how jet engine thrust comes about. The easy answer (but usually not clear to a nontechnical person) is Newton's 2nd Law of Motion for a control volume [1], written in words as

Sum of the Forces = Rate of Production of Momentum. (1)

The jet engine then is a momentum augmenter of the air flow through the engine, to produce a forward force for flight. The momentum flux of the engine exiting flow is greater than that which entered, brought about by the addition of the energy input from combusted fuel, and giving rise to engine thrust.

Interior Forces

One answer I have given to those not versed in Newtonian mechanics is to picture thrust as the summation of all instantaneous forces acting in an axial direction on the surfaces of engine parts exposed to gas flow through the engine. Thrust arises from pressure and frictional forces on these surfaces, e.g., blades, vanes, endwalls, ducts, etc.

This interior force view of thrust is easy to visualize but quite another thing to actually measure. In doing research on secondary flow in gas turbine passages, my former graduate student, Brian Holley (now a researcher at United Technologies Research Center) measured both steady state momentum changes and surface forces, in the much simpler case of a turbine blade cascade [2], shown in Fig. 1.

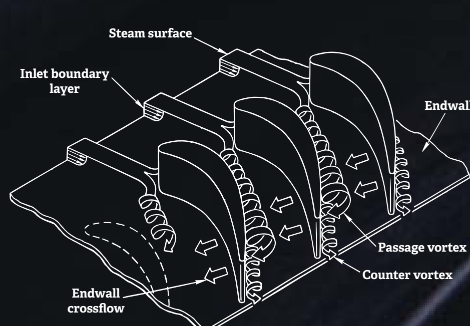

Figure 1. Sketch of a turbine blade cascade with an enhanced rendering of endwall secondary flow [2].

Using a five-hole pressure probe, Brian measured steady state momentum fluxes in and out of the cascade (the right hand side of Eq. (1)) in a few days. The cascade surface pressure forces were measured with an array of pressure taps, and using oil fringe interferometry (OFI), he painstakingly measured frictional surface forces (the left hand side of Eq. 1) which took several months. This yielded a surface force field for checking against CFD calculations, as well as satisfying Eq. (1) within experimental accuracy [3].

I tell the tale to show that measurement of thrust is relatively easily attained by measuring momentum changes, but would be excruciatingly difficult to do by measuring internal surface forces in an engine.

Engine Thrust Anatomy

This sets the stage for using Eq. (1) to calculate the distribution of thrust in a jet engine itself. This will show what part each engine component contributes to net thrust, with some surprises to those of us who might not have gone through such an analysis.

An excellent example of such an analysis is given in the very informative Rolls-Royce publication, *The Jet Engine* [4]. As shown in Fig. 2, the Rolls-Royce example consists of a single spool axial flow turbojet which has a net thrust of 11,158 pounds thrust (lbt), acting to left, for forward flight. (For comparison, most turbofan engines are in the 20,000-30,000 lbt range for single-aisle airliners, and in the 100,000 lbt range for larger airliners.)

The thrust values for each component in the Rolls-Royce single spool engine are shown in Fig. 2. The values (see [4] for details) are calculated from Eq. (1), where the mass

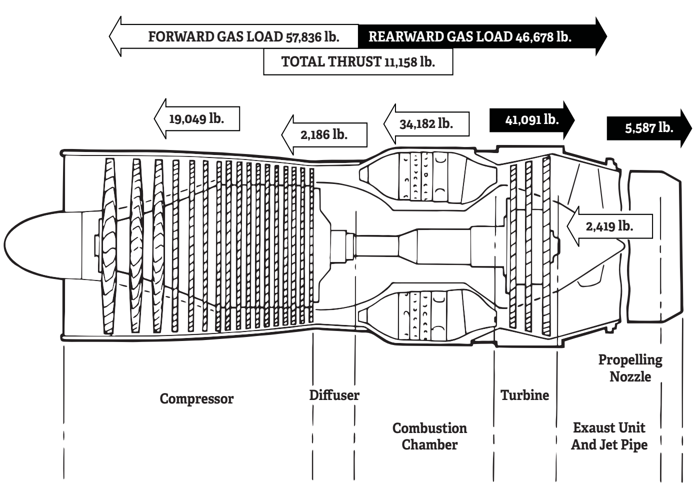

Figure 2. Thrust distribution for a single spool turbojet engine [4].

flow rate, flow areas and pressures are given for each component, and mean one-dimensional flow is assumed in the gas path. Following Fig. 2, an inlet-to-exit analysis yields the following:

1. As shown in Fig. 2, the single spool compressor, with a compression ratio of 7.4, yields a forward thrust of 19,049 lbt (171% of net thrust of 11,158 lbt).

2. From the compressor, gas path flow enters the engine case diffuser, where a pressure gain produces another component of forward thrust of 2,186 lbt (20% of net thrust).

3. Flow from the diffuser enters the combustion chamber, where it is heated at near constant pressure by the combusted fuel, with a large increase in exit flow area. This results in the largest value of forward thrust of any of the engine components, of 34,182 lbt (306% of net thrust).

4. The expanded combustion high temperature gases then enter the turbine (which drives the compressor) where they are accelerated and dropped in pressure and temperature, to produce a rearward thrust of -41,091 lbt (-368% of net thrust).

5. Turbine flow then enters the exhaust unit and jet pipe (Rolls-Royce terminology) where decelerating flow yield a small forward thrust of 2,419 lbt (22% of net thrust).

6. The engine gas flow finally enters the propelling nozzle, to increase its velocity and decrease pressure. As it exhausts to the atmosphere, it produces another rearward thrust of -5,587 lbt (-50% of net thrust).

I invite the reader to sum up the individual component contributions given in Fig. 2 and in items 1-6 above, to yield the net thrust of 11,158 lbt for this Rolls-Royce single spool engine. Newton's 2nd Law of Motion allows us to examine engine component behavior that exhibit both forward and rearward propelling forces, which results in the net trust our airline passengers have purchased.

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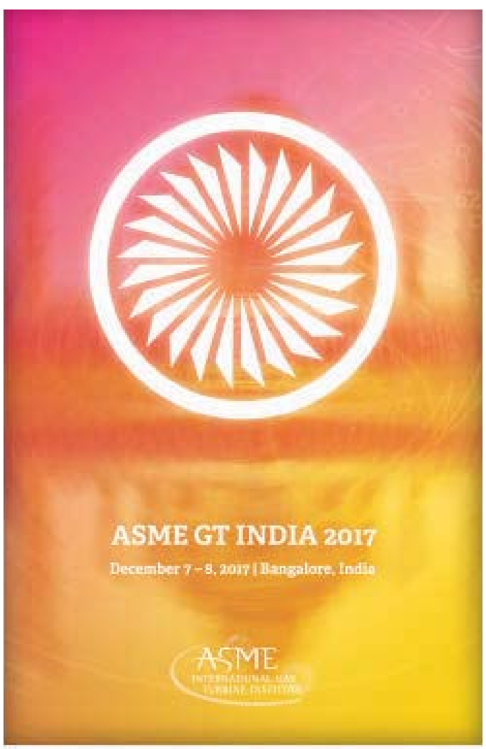
Recognizing Award Winners

at ASME 2016 Turbo Expo

Congratulations to all award recipients,

and thank you to all ASME IGTI committee award representatives whose work assists the awards and honors chair and the reading committee in the recognition of important gas turbine technological achievements.

Throughout the conference, ASME IGTI Committees honored more than 100 authors with Best Paper Awards for papers presented during ASME Turbo Expo 2015 in Montreal, Canada and over 20 Committee Outstanding Service Awards. Plaques were given to these individuals at their respective technical committee meetings.



Outgoing ASME IGTI Technical Committee Chairs

Aircraft Engine	Keith Boyer
Ceramics	Gregory Morscher
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Controls, Diagnostics & Instrumentation	Don Simon
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Electric Power	John Gülen
Heat Transfer	Nirm Nirmalan
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Young Engineer ASME Turbo Expo Participation Award Winners

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Jeffrey Defoe
Chiara Gastaldi
Giacomo Gatti
David Holst
Tobias Hummel
Simon Jacobi
Peter Kaluza
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Robin Prenter
Jorge Saavedra
Swati Saxena
Robert Schroeder
Vrishika Singh

Joshua Anderson

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David Gonzalez Cuadrado
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Shane Haydt
Qiangqiang Huang
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Zhiduo Wang
Juliane Wendler
Steven Whitaker
Michelle Wood
Manuel Würth
Lisa Zander

Recognizing Award Winners
at ASME 2016 Turbo Expo

2016 ASME R. Tom Sawyer Award
Dr. Nicholas Cumpsty, Imperial College London

2014 ASME Gas Turbine Award
"The Effect of Endwall Manufacturing Variations on Turbine Performance" - Dr. Robert Grewe, Siemens, Dr. Robert Miller, University of Cambridge, and Dr. Howard Hodson, Whittle Laboratory

2014 John P. Davis Award
"Modification of the Rolls-Royce Model MT5S Gas Turbine Engine Fuel Nozzle for Extended Fuel Flow Rates" - Jack Halsey, Rolls-Royce, Leonard L. Overton, Jr., Rolls-Royce , Dr. Philip E. O. Buelow, United Technologies Corporation and David Bretz

2016 Dilip R. Ballal Early Career Award
Dr. Carl Sangan, University of Bath

2016 Aircraft Engine Technology Award
Dr. Je-Chin Han, Texas A&M

2016 Industrial Gas Turbine Technology Award
Dr. Klaus Brun, Southwest Research Institute

Visit the ASME Turbo Expo web page for student travel opportunities for the 2017 Charlotte event.

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Large and Small Turbofans

Realizing Common Design Challenges

Jim Kroeger
Director—Business and Military Propulsion Engines:
Honeywell Aerospace

Historically, turbofan engines powering large transport aircraft have demonstrated much different design objectives than business-jet turbofans including thrust, range, mission-type, development cost, unit-price, maintainability standards, and production quantities. In the 1960's and 1970's, commercial transports incorporated 3 or 4 engines; they competed with propliners, targeted transcontinental or trans-Atlantic markets, and operated under the expectation of low fuel costs without emissions restrictions. During that era, business travel largely utilized "repurposed" military transports—even bombers! After the 1973 Arab oil embargo, and with the advent of government scrutiny on auto and aircraft emissions, jet engine manufacturers began to focus heavily on fuel economy and emissions. The Environmental Protection Agency was founded in 1970, and the first aircraft engine smoke standards were defined in 1973. In the mid 1960's, two functional parameters became the "guideposts" of turbofan engine architecture: "Bypass Ratio" (BPR) and "Thrust-Specific-Fuel-Consumption" (TSFC). By definition, "bypass ratio" is simply the net mass flowrate of air entering the fan which does not enter the engine core divided by the mass flowrate of air which does enter the core. "TSFC" is defined as the engine fuel mass flowrate divided by the propulsive thrust. Typically, engines with larger bypass ratios deliver superior TSFC and, incidentally, improved (reduced) emissions.

The earliest propulsion gas turbines were referred to as "turbojets". All of the engine inlet air was directed to the core, with thrust being generated by the change in momentum resulting from the change in gas velocity from the engine inlet to the core exhaust nozzle. The engine itself was a "core"; there was no bypass flow. Therefore, the bypass ratio of these turbojets was zero. Brayton Cycle efficiency is largely influenced by driving higher cycle pressure ratios and turbine inlet temperatures. Due to thermal and stress limitations for turbine components, internal pressures and temperatures for these early turbojets were very modest, such that all the work derived by the turbomachinery was consumed by driving the compressor without any excess power available to drive a fan. TSFC for a P&W JT3C (Boeing 707-100) engine at cruise conditions was about 0.9. Interestingly, the last generation of aircraft piston engines (e.g. the British Napier Nomad Diesel), with gear-driven slow-turning propellers, utilized bypass ratios ~ 100 and could demonstrate an effective TSFC ~ 0.45 at cruise conditions (assuming propeller propulsive efficiencies of about 0.85). In the mid 1950's, advanced aircraft piston engines weighed twice as much as the emerging turbojets. However, since the Boeing 707 maintained a long-range cruise speed almost "double" that of the Boeing 377, its piston-engine-powered predecessor, the range and total fuel consumption of the jet versus the propliner were about the same. But the 707 got there twice as fast! If the core of the jet engine could be made more "energetic", i.e., more powerful, then, possibly, the bypass ratio could be increased and TSFC reduced. From Figure 1, the TSFC benefits of higher bypass ratios can be visualized. A documentary could be written describing the relentless quest for increased bypass ratio enabled by engine cores capable of sustaining elevated compressor pressure ratios and turbine inlet temperatures.

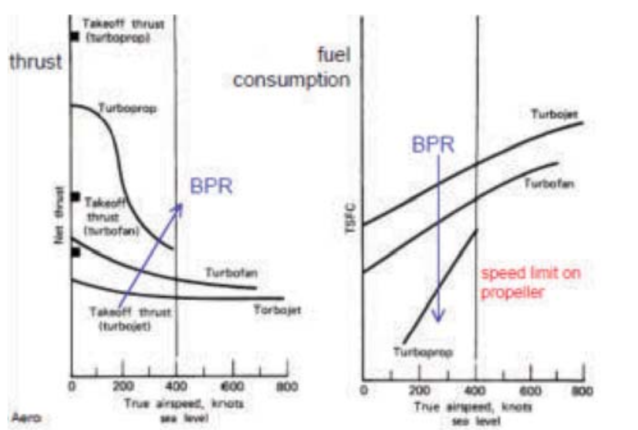

Fig.1 Increased Bypass Ratio Reduces TSFC at Optimal Airspeeds (University of Bristol Department of Aeronautics)

But how have the technologies required to deliver these energetic cores differed for large commercial transports compared to small business jets? Increasing compressor pressure ratio and/or "intercooling" drives a reduction in flowpath annular area, meaning compressor-discharge flow areas are reduced. At any thermodynamic station in the gas turbine the "corrected" flow is described by the relation:

$$W_{cor} = \frac{W_{mass} \times (T_{gas}{}^{\circ}R/519)^{0.5}}{(P_{static}\ \mathrm{lbf/in^2}/14.696)}$$

For a given mass flowrate (Wmass) a reduction in gas temperature (Tgas) or an increase in static pressure (Pstatic) will reduce the local corrected flow, Wcor. This effect is great for making engines smaller, improving cycle efficiency, and for enabling more energetic engine cores to allow higher fan bypass ratios. Conversely, though, as flowpath components become more "miniature", a heavy burden results on such design features as rotor-blade-tip-clearance and turbine-blade-cooling-passages. Manufacturing tolerances and the nature of "surface-to-volume" ratios (for turbine blade cooling) become critical for preserving aerodynamic performance and component durability. To prevent dangerous and efficiency-robbing compressor surge-and-stall phenomena, manufacturers of large, modern, high-pressure-ratio-engines have resorted to complex, active clearance control features in the last stages of the compressor and in the high-pressure turbine. But manufacturers of smaller, less-costly and less-sophisticated gas turbines, such as APU's and small business-jet engines, have advanced the implementation of surge-resistant centrifugal compressors (impellers) to replace the last 2 or 3 stages of a multi-stage axial compressor system. These "small" gas turbines typically operate with Wcor<5 lbm/sec.

Added to the requirement for managing surge and stall, flowpath area reductions present challenges to the design, fabrication and durability aspects of cooled high pressure turbine airfoils and disks. Surface-to-volume ratio scales approximately by $L^{(-2.0)}$ where "L" relates to the flowpath length scale. Figure 2 depicts how aggressively the surface-to-volume varies with turbine corrected flow. At constant turbine inlet temperature, increasing the core pressure ratio results in an increase in the turbine blade surface-to-volume ratio. Higher surface-to-volume ratio, in turn, leads to a requirement for a higher percentage of cooling flow to maintain blade metal temperature. Further complicating the turbine cooling challenge is the fact that film cooling holes distributed over the surface of the airfoil suffer from blockage effects caused by sand ingestion if cooling hole diameters are smaller than about 0.012". So, to avoid allocating too much cooling air, an economical distribution of small film holes is desirable but restricted by hole diameter. Prolific use of "thermal barrier coating" (TBC) has helped turbine designers compensate for the inability to distribute a large quantity of small diameter film holes over the turbine blade surface.

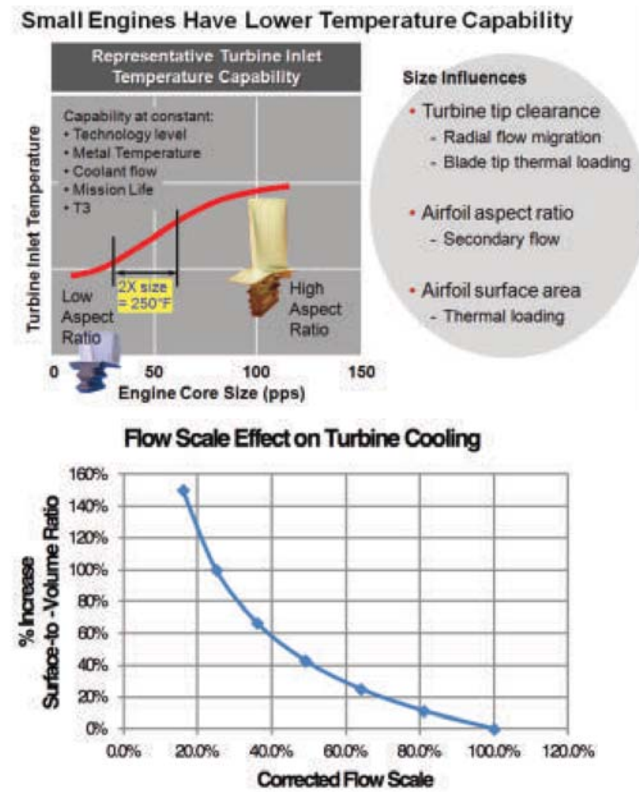

Fig.2 Decreasing Core "Corrected Flow" (for a constant mass flow) Increases Flowpath Surface-to-Volume Ratio

The historical trends in overall pressure ratio observed for both large and small turbofans have parallel slopes. Small turbofans lag behind the larger engines due to the miniaturization required for low flowrates characteristic of the smaller engines. These trends are qualitatively demonstrated in Figures 3 and 4, showing the growth in both the overall engine pressure ratio and turbine inlet temperature for several decades.

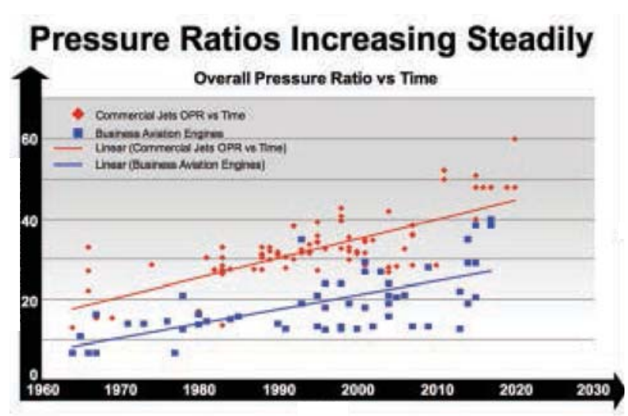

Fig.3 Overall Pressure Ratio Increases: Large Commercial and Business Turbofans

This article is continued on the next page.

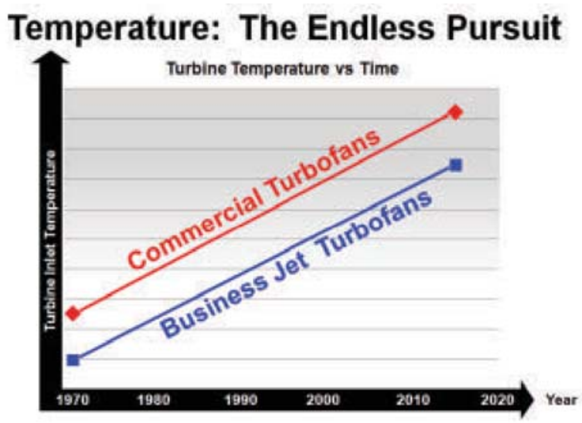

Fig.4 Turbine Inlet Temperature Increases: Large Commercial and Business Turbofans

In Figures 3 and 4 we find the latest large commercial turbofan engines demonstrating Overall Pressure Ratios (OPR) exceeding 50:1, with engines in the 2020's anticipating OPR's greater that 60:1! Compressor technology developments at GE/CFM with LEAP, at Pratt and Whitney with the Geared Turbofan (GTF), and at Rolls Royce with Advance and UltraFan may push OPR beyond 70:1! These 70,000 to 100,000 lbf thrust engines will have compressor-exit corrected flows that are actually driving down to levels currently sustained by much smaller business jet engines. Figure 5 captures these trends. Bypass ratios on these high OPR engines are expected to approach 15:1.

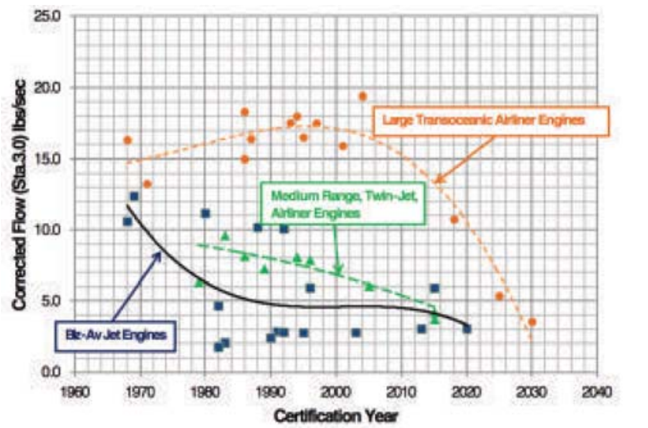

Fig.5 Very High OPR in Future Large Commercial Turbofan Engines is Yielding WCOR in the Range of Smaller Business Turbofans

The importance of high performance impeller designs and intricate turbine blade cooling concepts for very low compressor-exit corrected flows has not yet been fully appreciated!

This article was inspired by a presentation delivered by Mr. Jim Kroeger, at the 2015 ISABE conference. Mr. Kroeger is the Director of Military and Commercial Aircraft Engine Projects at Honeywell Aerospace.

Get Ready for ASME 2017 Turbo Expo
in Charlotte, NC, USA!

In 2017 three events come together bringing you one extensive conference located in Charlotte, North Carolina. Along with Turbo Expo, Power and Energy and the International Conference on Power Engineering (ICOPE) will convene in one venue, the Charlotte Convention Center. One registration fee will give you access to keynotes, plenaries, panel and tutorial sessions, workshops, and technical papers on topics such as: turbomachinery, aircraft engines, heat transfer, power generation, solar power, geothermal power, fuel cells, batteries, and nuclear reactor technology. The same variety will come to the exhibit hall with over 180 companies showing and describing their products related to these industries. You will not want to miss this event! During the closing ceremony of the 2016 exposition in Seoul, Conference Chair Mark Turner spotlighted the 2017 leadership team:

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Call for Papers

ASME 2017 Turbo Expo in Charlotte, NC

You are invited to offer a paper for publication at the ASME 2017 Turbo Expo Turbomachinery Technical Conference, June 26-30, 2017 in Charlotte, NC.

Prepare your abstract and submit it to the list of track topics for which ASME IGTI Technical Committees are seeking papers. Abstracts are due by September 12, 2016 and must be submitted online (plain text, 400 word limit) via the ASME Turbo Expo Conference Website at asme.org/events/turbo-expo

ASME IGTI Journals

If warranted by review, papers may also be recommended for publication in the Journal of Engineering for Gas Turbines and Power or the Journal of Turbomachinery.

Indexing

All ASME Conferences Proceedings are submitted for indexing to Scopus, Compendex, ISI Conference Proceedings Citation Index, and other major indexers. In addition, all ASME Conference papers are discoverable through Google Scholar search and all other major search engines.
Indexing publishers are independent organizations and determine which and when conference proceedings are indexed.

Publication Schedule:

Submission of Abstract
September 12, 2016

Author Notification of Abstract Acceptance
October 10, 2016

Submission of Full-Length Draft Paper for Review
November 21, 2016

Notification of Paper Acceptance
January 23, 2017

Copyright Form Submission Process Opens
January 23, 2017

Submission of Revised Paper for Review
February 13, 2017

Notification of Acceptance of Revised Paper
February 27, 2017

From the desk of:

K. Keith Roe, President

ASME | 2016 - 2017

To all ASME members and especially constituents of the International Gas Turbine Institute (IGTI) community and Turbo Expo:

As many of you know from our interactions, I was privileged to attend the recent 61st ASME Turbo Expo in Seoul, South Korea. Walking around the venue, it was more than apparent to me that this conference is the result of the tireless efforts of our paper authors, volunteer organizers, reviewers and dedicated staff. ASME and I cannot thank you enough for your time and commitment in making Turbo Expo the must-attend event for gas turbine professionals around the world.

Over the past six months, volunteers from within and outside of the IGTI community, along with ASME staff, have been operating as a Task Force to address concerns raised by the IGTI community in regards to their relationship with ASME as a whole. I must commend this group for their diligence and hard work in crafting a plan to satisfy all parties.

It is with great pleasure that I can now announce that the TEC Council has created a fifth Segment within the TEC Sector, to be known as the Gas Turbine Segment. As such, the new Segment will have a Segment Leadership Team (SLT) organized around the creation of new opportunities in the Gas Turbine arena, managing the current activities of the Groups operating within the Segment, and working with the SLTs of the other four Segments to provide the highest quality services to our stakeholders.

Additionally, the Task Force has set in motion a number of initiatives on behalf of the Segment, including the hiring of dedicated staff resources, upgrades and improvements to the online conference paper submission and review tool, and the creation of greater transparency and sharing of data between the SLT, the TEC Council and staff.

We believe we have made great strides in serving the IGTI community within ASME and we remain committed to IGTI. However, a few individuals that were associated with IGTI have created a separate society based in Europe called GPPS. There may be confusion over whether or not this group is related to ASME. It is NOT a part of ASME or IGTI.

Turbo Expo has never been stronger. Holding the conference for the first time in Asia this June, we achieved near record numbers in Seoul. More than 1,000 peer-reviewed papers were presented to the more than 2,700 attendees. We had 83 exhibiting companies and 16 corporate sponsors. With Turbo Expo returning to North America in 2017, and pairing it with the ASME Power & Energy Conference in Charlotte, North Carolina, we expect more than 4,500 attendees to participate. Turbo Expo is and will continue to be a flagship event for ASME and IGTI, and we will not allow anything to distract us from this goal.

Additionally, ASME has crafted a new enterprise strategy, which has required that we change the way we do business. We are now taking a more market- and constituent-facing approach, while also focusing on how we can become more integrated as ONE ASME. In the midst of the next industrial revolution and rapid changes to the world in which we live and work, ASME must be poised to be more relevant, engaging, and focused. ASME's new strategy focuses on advancing key mechanical engineering-related technologies. We will be providing more integrated resources to our technical communities, including more content, products, programs and services to advance our position as the go-to organization and thought leader. In addition to Turbo Expo being the technical conference for the gas turbine community, and our power and gas turbine-related Journals being the most recognized and prestigious outlets for research papers, we will pursue new ways to provide value and engagement to our academic, research, industry and government constituencies. I am very excited about where ASME is heading and think you will also be pleased by the value and service you receive going forward.

In closing, I encourage you to continue your fine work with Turbo Expo, to bring more gas turbine students and professionals into the fold, and to help ASME continue providing the highest caliber event related to gas turbines in the world. I thank you all for your contributions to ASME, IGTI, Turbo Expo and to making the world a better, safer place.

Kind regards,

Keith

INTEGRATED STEPPER MOTOR

JVL, BIRKERØD, DENMARK.

JVL has added Profinet industrial Ethernet capabilities toits NEMA 34 Series of integrated steppers with programmable controllers. Available in 4 torque ratings from 3 to 12 Nm, these compact integrated steppers include all necessary electronics within the IP67 rated motor housing. The 34 Series feature 409,600 steps per revolution for extremely smooth and quiet operation. The integrated PLC features 8 I/Os, RS-422 and RS485 connections for encoders, and point-to-point or multi-axis operations. The steppers are also available with separate SMC85 controller. Other options include electronic gearing, 9.53 mm (0.375 in.) or 14 mm (0.551 in.) diameter shafts, absolute multi-turn encoder, and planetary gear heads.

AIR GUN

EXAIR, CINCINNATI.

The new Ion Air Gun removes static electricity, contaminants, and dust from parts prior to labeling, assembly, packaging, painting, or finishing. It incorporates a high velocity air jet that uses a small amount of compressed air to entrain 80 percent of the total output airflow from the surrounding room air. An electrically energized emitter at the discharge end fills the entire airstream with positive and negative ions capable of neutralizing high static charges in a fraction of a second. The company says it can neutralize static electricity and cleans at distances of up to 15 feet. An optional regulator allows infinite adjustment of the air volume and velocity. A metal armored high-voltage cable can protect against abrasion and cuts, and the product also features an integrated ground connection and electromagnetic shielding.

PORTABLE THERMAL IMAGER

INFRATEC GMBH, DRESDEN.

The Nyxus Bird is a multifunctional infrared imager with an uncooled resolution of 640 by 480 pixels and a thermal resolution of less than 0.08 K. The imager enables users to easily toggle between the infrared channel and a visual monocular usable for daylight viewing. The ruggedized water- and dustproof housing is designed for ease of use and it copes with extended exposure to harsh environmental conditions. In addition the Nyxus Bird complies with U.S. military standard MIL-STD810F. On top of the basic Nyxus Bird functionality, an alternative version offered by InfraTec, the Nyxus Bird LR (long-range), enables the detection of humans beyond 4 km and ground vehicles beyond 7 km.

LEVEL MEASUREMENT

ENDRESS+HAUSER, GREENWOOD, IND.

The new Micropilot NMR81 is a radar with a transmission frequency of 79 GHz for level measurement in liquids, which makes it useful for high-accuracy custody transfer applications. The device emits a focused microwave beam with an angle between 3° and 4° to ensure safe and reliable measurements without any interfering signals, even in narrow tanks with baffles. That narrow beam angle enables the NMR81 to be installed relatively close to tank walls, and the technology permits very long measuring ranges of up to 70 meters. In custody transfer, the instrument measures up to 30 meters with an accuracy of ±0.5mm.

DATA LOGGERS

OMEGA, STAMFORD, CONN.

The Omega OM-CP-TEMP1000IS-A and OM-CP-RHTEMP1000IS-A intrinsically safe data loggers offer a compact design and portability which allows for placement into hard-to-reach locations. Features include a 316 stainless steel enclosure and a docking station, which means no need to remove end-caps to download data. Both data loggers are certified for Class I, Division 1, Groups A, B, C, and D and, non-incendive for Class I, Division 2 Groups A, B, C, D environments. That certification makes these devices ideal for EtO sterilization, environmental studies, medical and pharmaceutical, and numerous other hostile environment applications. Applications include monitoring temperature and humidity in sterilization processes, environmental studies, and chemical/petrochemical testing.

PRESSURE SWITCH

ASHCROFT, STRATFORD, CONN.

The Ashcroft B-Series NEMA 7/9 explosion-proof pressure switch is now available with a 316 stainless steel enclosure for demanding operating environments, such as salt water spray. The switches are IP66 rated and are approved for use in most NEC Class I and II hazardous locations. Each pressure switch can be fitted with a variety of diaphragm materials (including Monel for NACE applications) or with an external diaphragm seal to resist caustic or corrosive media.

PORTABLE DISPLAY

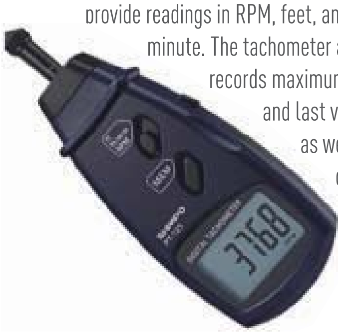
HEXAGON MANUFACTURING INTELLIGENCE, NORTH KINGSTOWN, R.I.

The TWIN-T10, produced by the TESA brand of Hexagon, is a portable display for inductive probes offering ease of operation for its users, as well as a clear and immediate graphical display of data. Due to the hemispherical form of the 200-segment analog scale, the display enables a clear analog and numeric reading of form variations. The new portable display also offers an operational time of more than 340 hours with standard AA batteries. The TWIN-T10 features maximum IP63 protection against dust and other particles, and is suitable for applications such as the geometry evaluation during fine adjustments and the assembly of mechanical parts.

CONTACT TACHOMETER

PAUL N. GARDNER CO., POMPANO BEACH, FLA.

The PT-120 is a velocity analyzing and measuring device designed for rotational machine inspection and process speed analysis. The PT-120 possesses a large backlit LCD screen to provide clear viewing in any environment. Users of metric models can obtain readings in either RPM, meters, and meters per minute, while imperial unit models provide readings in RPM, feet, and feet per minute. The tachometer automatically records maximum, minimum, and last value measured, as well as up to 96 data points during testing. It includes contact wheel and cone adapters.

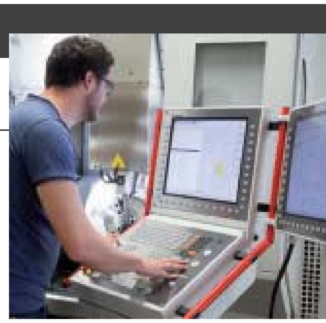


THERMOPLASTIC COMPOUND

RTP, WINONA, MINN.

RTP has introduced thermoplastic compounds that perform well in both conventional and extreme high pressure and/or temperature conditions. The company is marketing them specifically for use in oil and gas service backup rings. These structural compounds enable backup rings to perform beyond conventional high-pressure, high-temperature downhole conditions. The company also offers compounds formulated to reduce spring associated with backup rings machined from injection-molded stock shapes as well as cost-optimized RTP 2200 series PEEK compounds and RTP 1300 PPS compounds with mechanical properties suitable for conventional well conditions.

MILL-TURN CONTROL



HEIDENHAIN, SCHAUMBURG, ILL.

The TNC 640 is a high-performance mill-turn control with enhanced graphics, interpolation turning, and gear hobbing. The TNC 640's new graphics package includes a CAD viewer that opens any *.Step, *.Iges and *.Dxf file, and allows an operator to evaluate the workpiece at the control. To enable dynamic collision monitoring, the company has created a PC tool to merge and edit CAD files of components in the machining envelope and add them to the collision monitoring system. The interpolation turning feature enables a machine tool's linear axes move along a circle, while the cutting edge with the milling spindle is always oriented to the center of rotation (outside machining) or away from the center of rotation (inside machining).

WIRING ACCESSORIES

AUTOMATIONDIRECT, CUMMING, GA.

AutomationDirect has added a wide variety of wiring accessories including wire ferrules, disconnect terminals, and crimp terminals. The single- and twin-insulated wire ferrules are made of tin-plated copper. Single-insulated ferrules are designed to accommodate 20 to 1 gauge conductors; twin-insulated ferrules accommodate 20 to 6 gauge conductors. Available in 100-packs, crimp terminals include ring, fork, and pin terminals, as well as butt connectors for 20 to 10 gauge conductors. Disconnect terminals for 20 to 10 gauge conductors are constructed from copper-enhanced PVC and brass and are available in male and female bullet, partially and fully insulated PVC female, partially insulated PVC male, and partially insulated piggy back styles.

OPTICAL SPECTRUM ANALYZER

YOKOGAWA, SUGAR LAND, TEXAS.

The AQ6376 optical spectrum analyzer is designed to operate in the short- and mid-wavelength infrared regions, covering the wavelengths from 1,500 to 3,400 nm. The device uses an advanced monochromator design that enables it to separate spectral signals in close proximity to one another, and improves the dynamic range by reducing the influence of stray light. It features measurement speeds of up to 0.5 s/100 nm, a self-calibration procedure of less than two minutes, and a data-logging function for recording analysis results such as multi-peak measurements at up to 10,000 points per channel with time stamps which can be displayed in table and graphical formats. The AQ6376 is aimed specifically at the needs of academic researchers and optical device manufacturers with their own in-company laboratories, active in environmental monitoring and bio/medical industries.

LEVEL SWITCH

ENDRESS+HAUSER, GREENWOOD, IND.

The Liquipoint FTW23 capacitive point level switch is built for applications dealing with liquid media in the food and beverage industry. It is designed for hygienic processes such as water, beer, fruit juices, and milk and for use in storage tanks, mixing vessels, and pipes. All areas that are in contact with the process are made of robust 316L stainless steel material with PEEK insulation, making it suitable for cleaning and sterilization in place, and it can operate within a process pressure range of -14.5 to 232 psi and a temperature range of -4 to 212 °F. For cleaning and sterilization processes, it can withstand a temperature of 275 °F for 1 hour. The product complements the Liquipoint FTW33 conductivity point level switch, which is used in applications where build-up on the sensor is likely, and where a flush-mounted sensor is needed.

RING ENCODER

HEIDENHAIN, SCHAUMBURG, ILL.

Heidenhain introduced the ECA 4000 incremental ring encoder, the next generation of the company's ERA 4000 series. With the ability to provide a direct upgrade path for existing ERA 4000 applications as well as new applications, the ECA 4000 absolute series ring encoder offers several benefits and features for angular motion feedback. The ECA 4000 series is offered in outer diameters ranging from 104 mm to 560 mm so that machine designers can pass cabling and other items through the center of the ring to streamline their designs. Each ring has the three-point centering method, which allows the installer to locate the center of the drum to the center of the machine bearing within just a couple of minutes. In addition to the ENDAT 2.2 high speed pure serial interface, the scanning units on the ECA 4000 series also include Fanuc 05 and Mitsubishi 03-4 serial interfaces.

CABLE JUMPERS

MOLEX, LISLE, ILL.

Premo-Flex LVDS cable jumpers and assemblies are designed to deliver superior signal integrity performance over long distances. Like previously released options, the new custom cable jumpers and assemblies are durable, flexible, and available in a variety of pitches, cable lengths, thicknesses, and formats. Connector options for Premo-Flex LVDS cable jumpers and assemblies include: one-piece (15, 24, and 33 circuits), two-piece (30, 50, and 80 circuits), and one-touch LVDS (41 and 51 circuits). The cable jumpers and assemblies offer 100 Ω controlled impedance, making them suitable for high definition video displays, while the grounding terminals accommodate high-speed, high-frequency signal requirements. The jumpers and assemblies are gold-plated and can operate in temperatures ranging from -40 to +80 °C.

SWIVEL HOIST RINGS

CARR LANE MFG., ST. LOUIS.

New swivel hoist rings from Carr Lane Manufacturing have an electroless nickel plating that is suitable for many corrosive and outdoor environments. The safety-engineering hoist ring pivots 180° and swivels 360° simultaneously to allow lifting from any direction. The hoist rings are available with black oxide finish and have load capacities from 500 to 100,000 lbs.

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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.

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PUBLIC REVIEW DRAFTS
An important element of ASME's accredited standards development procedures is the requirement that all proposed standards actions (new codes and standards, revisions to existing codes and standards, and reaffirmations of existing codes and standards) be made available for public review and comment. The proposed standards actions currently available for public review are announced on ASME's website, located at http://cstools.asme.org/csconnect/PublicReviewpage.cfm.

The website announcements will provide information on the scope of the proposed standards action, the price of a standard when being proposed for reaffirmation or withdrawal, the deadline for submittal of comments, and the ASME staff contact to whom any comments should be provided. Some proposed standards actions may be available directly from the website; hard copies of any proposed standards action (excluding BPV) may be obtained from:

MAYRA SANTIAGO, Secretary A
ASME Standards & Certification
Two Park Ave., M/S 6-2A
New York, NY 10016
e-mail: ansibox@asme.org

ASME maintains approximately 500 codes and standards. A general categorization of the subject matter addressed by ASME codes and standards is as follows:

Authorized Inspections
Automotive
Bioprocessing Equipment
Boilers
Certification & Accreditation
Chains
Controls for Boilers
Conveyors
Cranes & Hoists
Cutting, Hand, & Machine Tools
Dimensions
Elevators & Escalators
Energy Assessment
Energy Storage
Engineering Drawings, Terminology, & Graphic Symbols
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SAN DIEGO STATE UNIVERSITY
Mechanical Engineering

FACULTY POSITION IN MULTISCALE MODELING OF MATERIALS

The Department of Mechanical Engineering seeks to fill a tenure-track position at the Assistant Professor level in the area of multiscale computational modeling of material systems starting Fall 2017. Mechanical Engineering is one of the four departments in the College of Engineering at San Diego State University with an EAC, ABET-accredited B.S. degree program, as well as M.S. and joint Ph.D. programs. The department has internationally recognized programs in material science and processing, mechanics, energy and thermofluids, bioengineering, MEMS, NEMS, sensors, robotics, dynamic systems and control. It is anticipated that the person will develop synergies with areas of existing research strength and exploit emerging areas of research by developing a vigorous externally funded research program in the general area of multiscale computational modeling of material systems. A demonstrated ability to collaborate across disciplinary boundaries is essential. The department shares with the College of Engineering and the University a strong commitment to excellence in undergraduate and graduate education. He or she is expected to supervise teams of undergraduate as well as graduate students. Applicants must have a demonstrated ability to teach undergraduate and graduate level classes in material science, materials processing, computational materials, and other related areas of mechanical engineering.

For more information about the department, college and university, please visit: http://mechanical.sdsu.edu, http://engineering.sdsu.edu, and http://www.sdsu.edu.

Applicants must have an earned Ph.D. degree in mechanical engineering or a closely related discipline. Applications must be received by November 15, 2016 to receive full consideration; the position will remain open until filled. Candidates must apply via Interfolio at http://apply.interfolio.com/36271. Questions may be directed to the Search Committee Chair at MEMMsearch@engineering.sdsu.edu.

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Penn Engineering

The School of Engineering and Applied Science at the University of Pennsylvania is growing its faculty by 33% over a five year period. As part of this initiative, the **Department of Mechanical Engineering and Applied Mechanics** is engaged in an aggressive, multi-year hiring effort for multiple tenure-track positions at the Assistant, Associate, and Full Professor levels.

We seek applicants with exceptional research achievement and future promise, a commitment to excellence in undergraduate and graduate education in mechanical engineering, and dedication to service and collegiality. Candidates should couple with the department's core disciplinary strengths in mechanical systems, mechanics of materials, fluid mechanics, and thermal sciences. The specific research areas for this search, and a link to apply for the position, can be found here: http://www.me.upenn.edu/faculty-staff/

The Department maintains strong collaborations with all other engineering departments, the School of Arts and Sciences, the Perelman School of Medicine, the Wharton School of Business, and the School of Design. Our faculty engage strongly with leading centers including the General Robotics, Automation, Sensing, and Perception (GRASP) Laboratory, the Penn Institute for Computational Science (PICS), and the Laboratory for Research on the Structure of Matter (LRSM). The Department encourages candidates who can leverage and add to these relationships. Successful candidates will conduct innovative, leading research programs benefiting from Penn's strong interdisciplinary tradition and excellent facilities such as the new Singh Center for Nanotechnology. The Department encourages applicants whose research aligns with the School's new strategic plan (http://www.seas.upenn.edu/PennEngineering2020). Candidates who enrich the diversity of our community are strongly encouraged to apply.

The University of Pennsylvania is an affirmative action/equal opportunity employer. All qualified applicants will receive consideration for employment and will not be discriminated against on the basis of race, color, religion, sex, sexual orientation, gender identity, creed, national or ethnic origin, citizenship status, disability, veteran status, or any other characteristic protected by law.

UNITED STATES AIR FORCE ACADEMY

ASSISTANT PROFESSOR OF ENGINEERING MECHANICS (#16-33DFEM)

The Department of Engineering Mechanics anticipates filling an Assistant Professor position not later than June 26, 2017. Responsibilities include teaching undergraduate core and majors' mechanical engineering courses to officer candidates, and performing research in mechanical engineering. The selected candidate will participate in academic advising, mentoring, accreditation reviews, and fulfilling departmental duties. The initial appointment will be three years; reappointments of up to four years each are possible.

By the time of application, an earned doctoral degree with demonstrated expertise is required in Engineering Mechanics, Mechanical, Aeronautical, or Astronautical Engineering focused in mechanics of materials, aerospace structures, finite element analysis, fatigue and fracture, composite materials, structural dynamics, experimental mechanics, or materials science. Essential qualities include integrity, industry, cooperation, initiative, enthusiasm, and breadth of intellectual interests. Successful candidates will have a strong commitment to undergraduate teaching.

The United States Air Force Academy is located just north of Colorado Springs, Colorado. It is an undergraduate institution that awards the Bachelor of Science degree. Its mission is to educate, train, and inspire men and women to become officers of character, motivated to lead in the United States Air Force and in service to our nation. The student body consists of approximately 4,000 men and women representing every state and several foreign countries. The curriculum includes core academic and professional courses and 26 disciplinary and interdisciplinary majors.

To Apply: Applications must be received by **October 14, 2016.** Go to www.usajobs.gov. Search for #16-33DFEM in the "Keyword" box, or type in "USAF Academy" in the "Location" box. Click "Search," then scroll down until you locate this position.

U.S. citizenship is required and the selected candidate must complete a security investigation. The U.S. Air Force Academy is an Equal Opportunity Employer.

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RECRUITMENT

ASME ONLINE VOTING PROCEDURES

ASME introduced an online ballot last year that members used for the election of Society officers, replacing the paper ballot that members traditionally received with the September issue of *Mechanical Engineering* magazine.

This September, ASME members can once again expect to receive an email that includes information on how to log into the ballot page, to be hosted on ASME.org, and vote for the Society's new president and members of the Board of Governors. ASME members who do not have an e-mail address, as well as members whose emails get bounced back, will be sent a hard copy ballot along with online voting instructions.

Members are advised to check their ASME records to ensure that their email address is up-to-date or to add an email address if one is currently not on file. To check on your current email address or update it, please go to your Membership and Benefits page on asme.org, or contact ASME Customer Care at (973) 882-1170 or (800) 843-2763.

Questions about the online voting procedure should be submitted to RuthAnn Bigley, ASME Governance, by email at bigleyr@asme.org. ME

CHALLENGE WINNER HONORED AGAIN

Sydney Vernon, one of the winners of the inaugural Future Engineers Challenge, has been honored once again. Vernon, a seventh-grade student from Open Window School in Bellevue, Wash., won the 2016 EngineerGirl Responsible Engineering Essay Contest, which was sponsored by the National Academy of Engineering.

Vernon took first place in the junior category of the Future Engineer 3-D Printing in Space Challenge last year with her Veg-01 system, a two-section, water-conserving planter that would allow astronauts to grow plants on the International Space Station.

Vernon took third place in the EngineerGirl competition's category for sixth- to eighth-grade students with her essay, "The Veggie: One Giant Leap." The paper detailed the benefits of the device she designed. ME

SIMS JOINS PANEL OF MASTERCLASS INSTRUCTORS

Former ASME president J. **Robert (Bob) Sims**, has joined ASME Training & Development's distinguished panel of ASME Code authorities and authors who teach a series of ASME MasterClass courses on Pressure Vessels and Piping Systems.

Sims will teach the new MasterClass, "Fracture Mechanics and Other Methods for Fatigue and Fracture Analysis of Pressure Equipment," which will launch this October during ASME Pressure Technology and Standards MasterClass Training Week in Houston, Texas.

Sims (at right) is an ASME Fellow who served as ASME president in 2014-2015. He is a widely regarded expert in risk-based technologies, high-pressure equipment, mechanical integrity evaluation, and Fitness-For-Service analysis. Sims' two-day MasterClass will focus on the fracture mechanics method of fatigue analysis of pressure equipment. The course, which will focus on practical applications instead of theory, is intended for engineers who work for pressure vessel manufacturers or firms that design, specify, procure, or are responsible for the inspection, maintenance or repair of pressure equipment in cyclic service.

ASME MasterClass courses are practical training sessions for experienced professionals that emphasize learning through the discussion of real-world case studies and practical applications. MasterClass instructors, considered to be elite in their fields of expertise, lead in-depth sessions that address current issues and best practices to inspire interactive discussions and group knowledge-sharing.

Sims joins a panel of peer experts who will be teaching courses during the ASME Pressure Technology and Standards MasterClass Training Week event. These experts include **David Osage**, lead author for *Design by Analysis Requirements in ASME Boiler and Pressure Vessel Code Section VIII, Div. 2—Alternative Rules*, who teaches a course of the same title; **Don Frikken**, past chair of the ASME Process Piping Code Committee, who teaches "Piping Failures: Causes and Remedies"; and **Jim Meyer**, current chair of the ASME Process Piping Code Committee, the instructor for "Piping Flexibility Analysis."

In addition to the Houston event, ASME Training & Development will also hold a similar program from Oct. 17 to 21 in Barcelona, Spain.

For more information on these Training Weeks events, or to register, visit http://go.asme.org/pressuretechtraining or contact Jennifer Delda, program/business manager, at deldaj@asme.org. ME

ASME ENTERS INTO AGREEMENT WITH THE ORGAN PRESERVATION ALLIANCE

ASME has joined forces with the Organ Preservation Alliance, a California non-profit, to establish a cooperative framework that will help the organizations collaborate on projects and initiatives for the healthcare and bioengineering industry sectors.

The Organ Preservation Alliance is dedicated to ending donor organ scarcity by conducting and promoting research in cryopreservation and other technologies for the long-term storage of human organs.

OPA, which is based at Singularity University Labs at NASA's Research Park in Moffett Field, Calif., is building on recent advances in cryopreservation research that could make long-term organ storage a reality and lead to such benefits as better organ matches, fewer rejections, lower transplant costs, and an increase in organ availability.

ASME and OPA signed the memorandum of understanding in late May.

The agreement aims to establish a cooperative framework that will help the organizations collaborate on projects and initiatives for the healthcare and bioengineering industry sectors.

It is also intended to bolster the ability of both organizations to achieve their shared mission of advancing, disseminating and applying healthcare and bioengineering knowledge and technology development from idea conception through product commercialization.

Through the agreement, ASME and OPA hope to improve communication and coordinate the exchange of technical information, share technical experts and technical content, encourage the engagement of ASME members and the technical community through live and on-line events. The organizations will also explore opportunities to collaborate in the development of conferences, technical seminars, workshops, publications, roadmaps, training courses, and other related activities.

For its part, ASME intends to support OPA by contributing to relevant white papers and publications; publicizing organ banking news, white papers, publications, and conference and workshop information; and participating in the Alliance's events and activities.

ASME also agreed to be one of the sponsors of the OPA roundtable workshop, "Emerging Technologies in Organ Preservation," that was held in June, and to participate in the Organ Banking Summit at Harvard Medical School in 2017.

OPA will collaborate with ASME by providing the Society with input and guidance on market trends, future directions, and community needs within the organ banking and tissue engineering area. The organization will also offer content and program development assistance for relevant ASME conferences and events, and promote relevant ASME conferences, workshops, publications, and other content.

To learn more about the Organ Preservation Alliance, or for more details on the Roadmap to Organ Banking, visit www.organpreservationalliance.org.

For more information on Memorandum of Understand or the "Emerging Technologies in Organ Preservation" workshop, contact Christine Reilley, director, ASME Emerging Technologies, by e-mail at reilleyc@asme.org. ME

REED SELECTED TO RECEIVE GLEASON

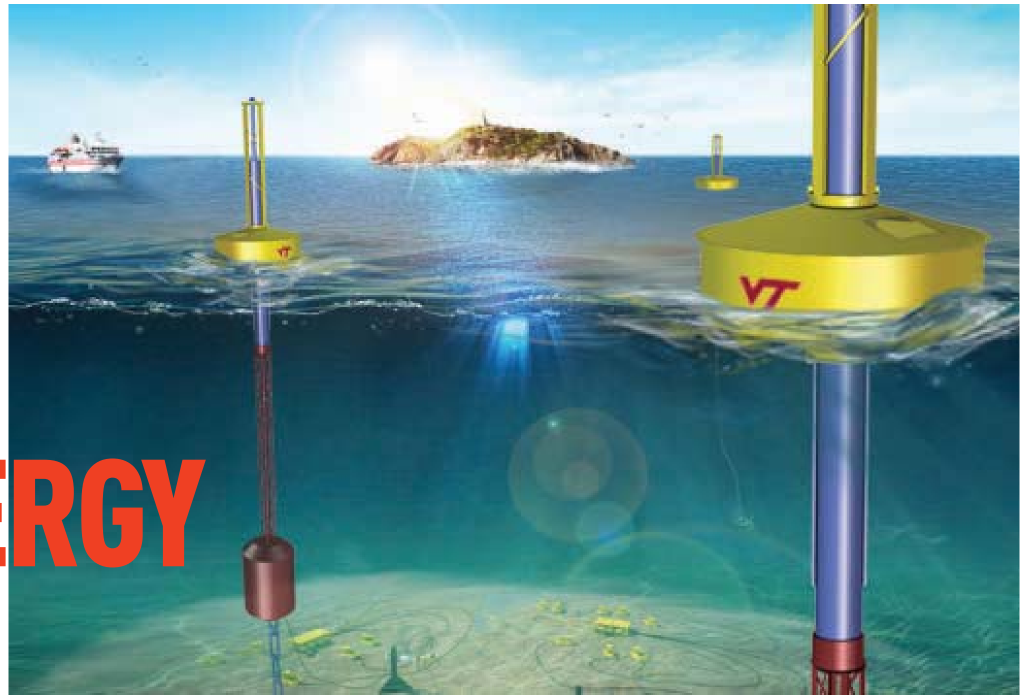
ASME Fellow **Helen L. Reed**, a professor in the aerospace engineering department at Texas A&M University in State College, has been selected to receive the 2016 Kate Gleason Award from ASME.

The award recognizes the contributions of distinguished female leaders in the engineering profession. Reed (left) is being honored for her lifetime achievements in the fundamental understanding and control of boundary layer transition for high-efficiency aerospace vehicles and in pioneering small satellite design and implementation. A member of the National Research Council's Aeronautics and Space Engineering Board, Reed is widely regarded as an expert in hypersonics, energy efficient aircraft and small satellite design. She has received a number of professional awards and honors, including the Atwood Award from the American Society for Engineering Education and the American Institute of Aeronautics and Astronautics. ME

HAN WINS AIRCRAFT ENGINE AWARD

ASME Life Fellow **Je-Chin Han**, distinguished professor and holder of the Marcus C. Easterling Chair in the department of mechanical engineering at Texas A&M University, has been named the winner of the ASME Aircraft Engine Technology Award for 2016. The award, which was presented to Han during the ASME Turbo Expo in Seoul, South Korea, recognizes his contributions to the field of air-breathing propulsion through inspiring leadership, education, and research. During the conference, Han also delivered the 2016 Aircraft Engine Technology Award Lecture, "Turbine Blade Cooling Research at Texas A&M 1980-2016." He has served as editor, associate editor and honorary board member for eight heat transfer-related journals. Han served as ASME K-14 Gas Turbine Heat Transfer Committee chair from 2004-2006 and ASME K-3 Heat Transfer Honors and Awards Committee chair from 2005-2006. ME

New wave-energy harvesters use a unique mechanical system to generate 500 watts of power in their initial launch.



RIDING AN ENERGY WAVE

Professor Lei Zuo isn't one to rest on his laurels. He won ASME's Thar Energy Design Award in 2015 for his pioneering work on large-scale energy harvesting and was named an ASME Fellow about six months later. Early this year he improved his ocean-wave-energy harvester design, incorporating significant changes that helped him win a $2 million Department of Energy grant to continue the project.

"Seventy percent of the Earth's surface is covered with water and 53 percent of its population lives near a coast. The potential is huge," said Zuo, who started building his first wave-energy harvester in 2012 at Stony Brook University and is now creating new versions as director of the Energy Harvesting and Mechatronics Lab at Virginia Tech. "We want to make broader impacts," he said.

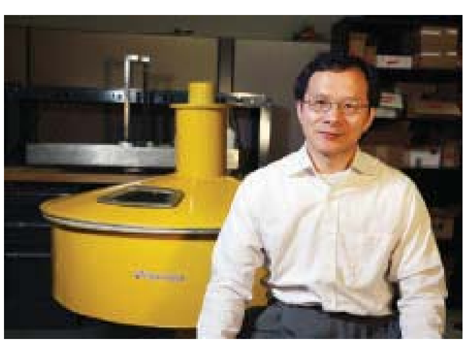
Zuo's new harvester works on much the same concept as previous designs. A shaft, which is attached to an anchor or other submerged object that's moored to the seabed, extends through the middle of a buoy. As waves pass by, the buoy bobs up and down and a power takeoff system inside its shell converts that linear motion to rotation to drive a generator. Zuo refers to that takeoff system as a mechanical motion rectifier (MMR) and says it's one of the most innovative components of the harvester.

The original MMR was made up of two rack and pinion systems, each with its own one-way clutch. The racks were mounted to the shaft, and the motion of the buoy made the pinions roll up and down against the rack. The one-way clutches allowed only one pinion at a time to engage the shafts driving the generator, so that the rotor turned only in one direction. As a result, the shaft is almost always turning and driving the generators, which achieved over 60 percent efficiency in tests. The harvested energy can be stored in a battery or transmitted directly to an electrical grid.

Zuo recently replaced the rack pinion system with ball screws. Pairs of spiral-grooved shafts push and pull through collars connected to a drive train that turns the generator. The grooves are cut in opposite directions to engage the collars one at a time, so that the drive is moving in the same direction whether the buoy is floating up or down. Zuo expects the ball screw system to be significantly more efficient at translating linear motion to rotational motion. It will also require a lot less maintenance, something that appealed to the DOE. He also added a flywheel to the MMR, which further increases the efficiency. If high ocean turbulence causes the ball screw to move too fast, it disengages and the fly wheel takes over to store the kinetic energy.

For the DOE project, the Virginia Tech team plans to launch a new 500-watt unit of a 1.2-meter buoy this fall, followed by the launch of a 10 kW device housed in a buoy 5 meters in diameter next year. The team will apply data collected from those to a 25-meter system that will generate a megawatt of power. As part of the DOE grant, the power takeoff must achieve minimum gains of 50 percent in reliability and 25 percent in power output.

"The U.S. is so far behind in wave energy harvesting that we have to catch up," Zuo said. ME



Lei Zuo plans to increase the size of his wave energy harvester to 25 meters.

JEFF O'HEIR