MECHANICAL ENGINEERING

THE MAGAZINE OF ASME

No. 08 138

Technology that moves the world

TINY ENGINES FOR MICROSATS

An innovative, 3-D printed ion drive can power a satellite small enough to fit in a breadbox.

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AUGUST 2016

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A WALL OF FANS CLEANS AIR

SOMETIMES A NEW TECHNOLOGY DOESN'T HAVE TO BE SUPER-COMPLICATED. For example, Carbon Engineering is designing "air-capture plants" that use walls of fans to strip carbon dioxide from the atmosphere, thereby reducing levels of that greenhouse gas. Those plants will be scalable and can be built anywhere in the world, including unpopulated areas like deserts. They would also be beneficial in urban areas for capturing CO_2 released by cars and trucks.

UNDERSTANDING THE MECHANICS OF TISSUES

A mechanical engineering professor at Columbia University is evaluating structural loads, not for cars, airplanes, or bridges, but for tissues in the human body to aid in early diagnosis and treatment of disease and other medical conditions.

VIDEO: THE CHALLENGE OF MANUFACTURING LIGHTER VEHICLES

Cleaner vehicles with higher gas mileage are usually made from lighter and more efficient materials. Bruno Barthelemy of Ford Motor Company describes how one of the world's largest automakers is accomplishing this.

GET YOUR 3-D MOTOR RUNNING

Additive manufacturing has certainly helped individuals make all sorts of unexpected objects. But a fully functional motorcycle? If only Evel Knievel could have had the chance to experience the 90 percent 3-D printed polymer construction recently developed by Kent David Russell of TE Connectivity.

NEXT MONTH ON ASME.ORG

DRONES TAKE FARMING TO A WHOLE NEW LEVEL

FAA approval of unmanned aerial vehicles for commercial use is speeding up the adoption of "precision agriculture," a technique involving crop surveillance and the use of high technology in crop spraying

VIDEO: BRINGING HUMAN-CENTERED DESIGN TO MANUFACTURING

What is human-centered design, and how does it impact manufacturing? David Bishop, lead desiger and researcher at MAYA, discusses how engineers can use the principles of human-centered design to build products.

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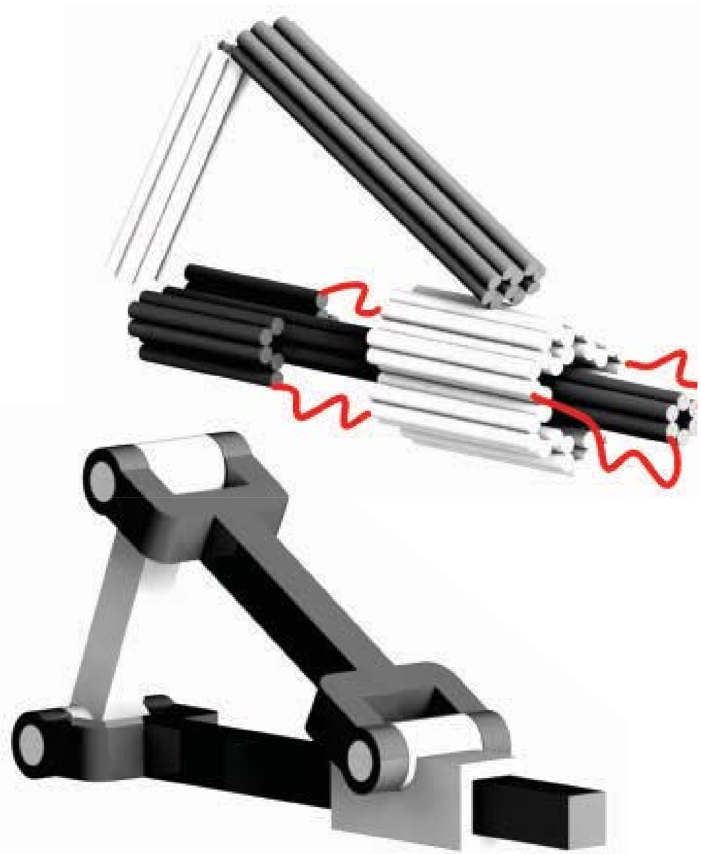

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Give me the place to stand, and I shall move the earth
—Archimedes

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John G. Falcioni
Editor-in-Chief

ENABLING TECHNOLOGY FOR A BETTER FIT

With the trepidation of an old dog in a new home, I strapped a Fitbit on my wrist a few months ago hoping I'd find its religion. I haven't looked back since.

Mind you, it's not like the activity-monitoring device has turned me into a triathlete. I'm no more an avid runner or cyclist today than I was at the beginning of the year, but I've certainly become more aware of my activity. My Fitbit tells me how many steps I take, how many miles I walk, how many stairs I climb, how often my heart beats, and how long and how well I sleep. It also counts the calories I burn and tells me when I'm slacking off from my daily routine so I can get back to my personal peak performance level.

With the sensing device on my wrist I'm more motivated to opt to walk up and down stairs instead of taking the escalator; I go for more frequent and longer walks than I used to; and try to get up from behind my desk now and do a little stretching every hour or so.

I won't say that the goal of 10,000 steps daily, recommended by the American Heart Association, has become an obsession, but it's now an objective I care about.

My Fitbit is essentially my personal Internet of Things.

Like a Fitbit for the factory floor, the industrial IoT, with its network of Internet sensors and tracking technologies, monitors the health of machines and manufacturing equipment. It detects malfunctions, deviations, and malnutrition when supplies are low.

But unlike personal devices that will track a person's activity regardless of age or fitness level, it's not always easy to connect or retrofit plant equipment in a way for it to embrace and engage the IoT. Connecting a Fitbit or other similar health tracking device to its enabling software is a lot easier than connecting a milling machine to the cloud.

In some cases, it isn't even that the equipment is too old to connect to sensors. Some equipment as young as 20 or even 10 years old can't easily be hooked up to monitoring sensors and connect it to the Internet. Some manufacturers also fear that sensors can occasionally be finicky and make plant equipment difficult to troubleshoot.

That said, a recent *IC Market Drivers* report projected that worldwide systems revenues for applications connecting to the IoT will nearly double between 2015 and 2019, and could be more than $124 billion by 2020.

The report, which is published by IC Insights, a semiconductor market research company, said that during that same time period, new connections to the IoT could grow from about 1.7 billion in 2015 to nearly 3.1 billion in 2019.

Ultimately, the business case for the IoT is there: Reduce manufacturing costs and improve ROI, and that's true even in cases when investments are necessary to retrofit equipment.

I've lost 10 pounds since I've been wearing my tracking device, so I've seen the ROI of being connected. But like some manufacturing equipment, I too get a little finicky, especially on those days when my Fitbit is telling me something I don't want to know. **ME**

FEEDBACK

How concerned are you about privacy as we get more connected to the Internet of Everything? Email me.

falcionij@asme.org

MARCH 2016

Reader Salisbury asks how responsible engineers are for user mistakes.

« One reader backs the magazine's coverage of ethanol. Another calls for engineering students to study business methods.

ENERGY IN ETHANOL

To the Editor: I am writing to correct the misconceptions about energy and its use found in a letter to the editor ("Potential of Ethanol," March 2016).

The lower heating value is the usable energy in that fuel. If the chemical composition contains oxygen, it is partially oxidized. For example, ethane has a higher energy content per pound than ethanol. Both ethane and ethanol are inferior to gasoline in the amount of usable energy, as represented by the lower heating values of the fuels.

The insanity is that we pay a premium price for ethanol because of the subsidies that support its use.

The claim in the letter that *ME* is lazy and culpable in its coverage of ethanol does not pass the smell test. I assert that *Mechanical Engineering* is not derelict in its responsibility to ASME members and the general population, nor is its stance political.

George J. Silvestri, Jr., *Souderton, Pa.*

ETHICAL QUESTIONS

To the Editor: The March 2016 Workforce Development column ("Ethics Revisited" by James G. Skakoon) brought up GM ignition switches and the Ford Pinto as unethically designed products. But were GM engineers unethical when they designed an ignition switch that was easy to use but could not withstand the torque applied when car owners added the weight of gadgets to the key fob chains? Do car owners have no responsibility when modifying their vehicles?

Certainly GM never told owners to add junk to their key fobs. Must GM add a note in its car manuals stating, "Do not modify your car in any way or death may result?" Was it unethical to not warn owners? I don't think so.

As for Pinto, I worked briefly as a Pinto suspension engineer, and my remembrance is that the accident rear impact speed was about 50 mph, well above the government requirement. So here's the question: At what impact speed should an "ethical" engineer have designed and tested the Pinto for fuel system integrity in a rear crash? The "bullet car" could be traveling at 110 or 150 mph in a highway situation. Is that sufficient or is the national highway speed limit of 70 mph sufficient?

Absent an answer, ethics was not the issue in that case.

Roy S. Salisbury, Jr., *Rochester, Mich.*

MULTIDISCIPLINARY NEEDS

To the Editor: I enjoyed reading "Robots at Work" (April 2016). It took me back to the Department of Defense Directive 5000.51 "Total Quality Management Guide," published in February 1990. Volume II of that guide provided a performance improvement profile showing the three ages of economic development: The Agricultural Age, the Industrial Age, and the Systems Age.

The Systems Age started with the space program in the early 1960s. It is what W. Brian Arthur calls the "Second Economy."

The Second Economy or Systems Age requires the development of multidisciplinarians whose background should be a combination of both science and business. In addition to studying the STEM courses, those multidisciplinarians should also study finance, accounting, management, and economics, what may be termed the FAME courses.

I think engineering schools should incorporate business courses in their undergraduate programs to give the students a head start in the business world. That will provide them with the flexibility of functioning in the new economy.

Ibrahim A. Ashie, *Conway, S.C.*

DIRTY BIRDS

To the Editor: There is irony in the story title, "Clear Skies Ahead" (June 2016). Actually, it should read "Dirty Skies Ahead," because jet engines produce prodigious amounts of CO_2 and NO_x in the upper atmosphere where they may remain for years. Thousands of tons of those greenhouse gases are discharged at increasing rates as air transportation increases.

Jet engines are unique among carbon-burning engines as they have no emission standards. Air transportation was not even mentioned in the Paris Conference. This oversight may be unintentional, but jet engines are known to be the largest single source of NO_x, which is a far more potent greenhouse gas than CO_2.

Why is air transportation given a free ride on emission standards?

Henry Huse, *Norwalk, Conn.*

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.

PERFECTLY CAST

LESS MATERIAL MAKES FOR BETTER SUPPORT FOR BROKEN BONES

Jason Troutner knows casts. Long before he signed on as chief technology officer of Cast21, Troutner endured multiple surgeries and sports injuries that required him to spend about three years wrapped up in more than 50 fiberglass casts. He suffered through itching, odors, and muscle atrophy—and moped around when he couldn't swim with his pals.

Troutner, together with biomedical design engineer Ashley Moy and electrical engineer Justin Brooks, founded Cast21 to reduce the discomforts faced by millions of people who end up in some type of cast every year.

"Materials used in fiberglass casts aren't waterproof; they absorb and trap water. Those are the two main problems we set out to solve," said Troutner, who met Moy and Brooks during an engineering design class at the University of Illinois, where they partnered on the project. "Fiberglass casts are poorly engineered and not patient-friendly. For an engineer, it seems like such a lazy and impractical solution."

The fiberglass wrapping of modern casts is water resistant (unlike the old plaster ones), but wearers still can't allow the cotton padding underneath to get wet. To fix that problem, the team developed a cast made from interconnected silicone tubes that harden after they're injected with resin. The cast's lattice design immobilizes the bone, yet leaves most of the skin exposed, giving it room to breathe. The gaps also allow room for electrical stimulation electrodes, which can prevent muscle atrophy and help fractures heal.

Other groups have developed prototypes of customizable casts that can be manufactured using 3-D printers. But many of the orthopedic surgeons and physicians the Cast21 team spoke with during its market research said they were unwilling to invest in the resources needed to support a 3-D printing infrastructure in their offices. "From a business standpoint, it's impractical," Troutner said, adding that the process would also take too much time with today's 3-D printers, given that each cast has to be customized to fit individual limbs.

Instead, Cast21 developed a one-size-fits-all approach for leg and arm casts. The cast starts off as a mesh sleeve made from a highly flexible silicone that conforms to the shape of the limb in much the same way a foam fruit sleeve wraps around a small apple or a large pear. A physician or nurse slips the Cast21 sleeve over the patient's limb, properly positions the limb and cast, and injects the hollow tubes with a polyurethane resin. The resin hardens within 15 to 20 minutes to support the broken bone, yet the silicone material

A new type of cast starts as a mesh of silicone tubes. Once fit around a broken limb, the tubes are filled with polyurethane resin.

still provides cushion against the skin. The cast is about 70 percent lighter than a fiberglass cast, which usually takes between 25 and 30 minutes to harden, longer if the patient will be walking on it.

To come up with initial ideas for a strong yet flexible design, Troutner used an incredibly sophisticated process—he typed "cool mechanical structures" into Google. He came across basketball and fruit nets, the Eiffel Tower, finger traps, and a variety of bridges. His friend, an aerospace engineer who specializes in finite element optimization, then created an optimization program to match the best design with the ideal materials.

"As a mechanical engineer, I had to find out how the segments would play together to provide the strongest support," Troutner said. "I had to make sure the structure would stand up to any force on the arm or leg."

Cast21 has filed for a provisional application patent and is waiting for U.S. Food and Drug Administration approval. It is also working with medical device accelerator ZeroTo510 in Memphis to build a sales and marketing structure. Meanwhile, Troutner is tweaking the silicone and resin formulas for an even stronger, more comfortable cast. Unfortunately, the team has yet to discover a good way for people to sign it. **ME**

JEFF O'HEIR

A NEW WAY TO CLEAR THE AIR

INDOOR AIR IS, ON AVERAGE, FIVE TIMES as polluted as outdoor air. It can worsen allergies and asthma, and over the long term can cause respiratory diseases and cancer. Yet today's air purifiers and HVAC systems use decades-old filtration technology, and they often miss microbes, pollen, mold, and nasty airborne chemicals.

A new air-purifying technology could help. Instead of a filter, the device blows air over a photoactivatable catalyst to create highly reactive chemicals that destroy volatile organic compounds, microbes, pollen, and other allergens.

Back in the mid-1990s, Yogi Goswami, a solar energy researcher who directs the Clean Energy Research Center at the University of South Florida, had a personal reason to switch gears and investigate air purification technology. His son Delip, who's now 35, had severe asthma and allergies as a boy, and conventional air filtration devices did not ease them.

In his previous work, Goswami helped develop a solar-powered water-purification technology that used sunlight to activate a catalyst, which oxidized organic chemicals to destroy them. "In air, you have mostly organic chemicals, too," said Goswami, including biomolecules in air-borne pollen, animal dander, mold and microbes. "I saw that we could oxidize them as well," Goswami said.

Over almost two decades, Goswami and his students and colleagues optimized air flow, light source, catalyst chemistry, and more. The resulting device, called the Molekule, uses a fan to pull air over a nanocatalyst—a nanometer-scale material with controlled molecular properties that catalyzes a chemical reaction.

Harmless long-wavelength ultraviolet light shines on the catalyst, which is a semiconductor. The light kicks out an electron, leaving an electron hole that oxidizes water vapor to create highly reactive chemicals called hydroxyl radicals, which attack and destroy VOCs, pollen, and microbes.

A cutaway view of the Molekule air filter.
Photo: Molekule

In tests by Goswami's San Francisco-based startup, also called Molekule, the device removed all 3.9 million E. coli bacteria that were aerosolized and sprayed into it. In a company-run trial of 28 allergy sufferers, the device also eased self-reported allergy symptoms to the same level as non-sufferers.

The company began selling the device to consumers in May. In time, it hopes to adapt the technology for HVAC systems and in cars and airplanes, Goswami said. **ME**

DAN FERBER

MORE CRUSHES ON THOR

A technician works on Thor's central power flow assembly.
Photo: Randy Montoya / Sandia National Laboratories

The famed Z machine at Sandia National Laboratories is a massive, monstrous beast. The fusion-research device sends powerful, 100-nanosecond electrical pulses through thin tungsten wires to create a plasma capable of crushing material with a pressure of 5 million atmospheres. But to do that, the accelerator requires 10,000 square feet of space and a significant amount of maintenance between bursts. Any scientist hoping to give a dollop of deuterium a good squeeze only gets the chance a few times a year.

To remedy the situation, Sandia is building Thor. Where the Z machine uses huge capacitors that need enormous switches to trim a pulse down to 100 nanoseconds, this smaller accelerator will use new, smaller capacitors called bricks that don't need giant switches to shorten the pulse and require much less upkeep. The bricks will allow the facility to be a fifth the size of the Z machine and some 40 times more efficient. "Scientists are getting two or three tests a year on the Z machine," said David Reisman, the lead engineer and project manager for the new accelerator. "I could get 10 shots a week on Thor." The higher volume of shots would mean much larger data sets and the development of diagnostics.

> **"SCIENTISTS ARE GETTING TWO OR THREE TESTS A YEAR ON THE Z MACHINE. I COULD GET 10 SHOTS A WEEK ON THOR."**
> **—DAVID REISMAN, LEAD ENGINEER AND PROJECT MANAGER, SANDIA NATIONAL LABORATORIES**

The bricks will also allow Thor's pulse to be fine-tuned to avoid shock waves that would otherwise alter whatever material was being examined. "We can change the ordering to shape things in the way that we want, like a piano. We have individual notes that we can use to get what we want," Reisman said. "So we can study the material in the unmelted solid form, where it still has atomic structure and strength and things like that." The ability to "play" the pulse shape will also allow researchers to examine how materials cross phase boundaries and go from one crystal structure to another.

Major advances in capacitor and switching technology have given rise to the bricks. Highly reliable and efficient, it's their

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CRUSHING POWER

size that determines the size of the pulse. So each brick has less current: 50,000 amps. They're added together to get the desired current. "So that's the tradeoff," Reisman said. "You don't have these big pulse-forming lines and these big machines but then you have a lot of these guys you have to trigger separately."

The smaller size means Thor's crushing power is limited to a mere million atmospheres. But that's enough for most of the researchers hoping to put pulsed power to use. The Z machine's powerful "Z pinch" was initially conceived of as a tool for researching fusion. Recently, though, the majority of tests run on it have been isotropic compression experiments, which don't need all five million atmospheres. If those researchers could do their work on a smaller machine, it would free up the Z machine for fusion-specific work.

Already universities are clamoring to get their hands on Thor or its offspring. But they'll have to wait until Sandia has proved its feasibility. "We're going to validate things here and then pursue that," Reisman said. Once Sandia has finished working out the bugs in the junior accelerator, researchers are likely to achieve a better understanding of what's in the center of our world as well as worlds more distant.

"People want to study materials that are important to geophysics and to planetary physics, where there's a lot of uncertainty in those material properties," Reisman said. "This is important because they are discovering thousands of these planets outside our solar system, and to really understand the formation of the planets and their composition, they need to have accurate data on material under high pressure.

"My hope for this machine is that it will help that effort." ME

MICHAEL ABRAMS is a New York-based technology writer. For more, go to ASME.org.

FIVE INNOVATIVE MATERIALS

Blocks and bricks made from locally available sources can build durable structures.

Pricey Energy Star equipment and rooftop green gardens are impossible to install in every home in developing countries. But smaller scale and more appropriate materials are available, and they can build sustainable, strong homes anywhere in the world. From design to construction to operation, the process should not only consider sustainability, but also the environment and the appropriate needs of the users.

Structural engineering dictates the material and the geometry of the structure, which, in turn, dictate the resources and construction methods used in a project. By choosing the right materials, structural engineers can improve a project's sustainability. And they can satisfy the needs and safety of a building's users with innovative and appropriate designs. Resources also should be easily accessible to the building's users, and the construction process should be done with the community, ideally educating people to be self-sufficient.

Some innovative materials and techniques suitable for sustainable and appropriate structural engineering include:

SEISMIC RETROFITTING: After the January 2010 earthquake in Haiti, damaged structures needed to be rapidly repaired or rebuilt. Retrofitting is a cost-effective way to improve upon existing damaged structures to reduce accidents and deaths from future earthquakes.

In Haiti, several retrofitting methods were used to improve structural integrity. Those methods include increasing the shear wall density to resist seismic loads on structures, repairing deterioration due to corrosion or sulfate attack, and strengthening ground conditions and foundations in liquefaction zones. Most importantly, the local community of Haiti also helped with the retrofitting process, which means trained local engineers now can work independently on future reconstruction or retrofitting projects. The Denver-based NGO Build Change has made nearly 28,000 buildings safer in Haiti by using retrofitting techniques.

Three compressed earth blocks.

COMPRESSED EARTH BLOCKS: The Earth Block Resettlement Project in Mozambique used compressed earth blocks (CEBs) for building their resettlement structures. CEBs are composed of mixed dry subsoil, clay, and waste aggregates, such as building rubble, compressed with a machine press or hydraulic compactor at high pressures. CEBs have a compressive strength that exceeds the requirements for regular cement blocks. Most importantly, they are sustainable since the earth blocks used only 8 percent cement, a material that requires high carbon emissions to produce. Because only soil slurry is used for bonding instead of cement mortar, the construction process is also faster, and low technology can be used to manufacture them. CEBs also have better insulation properties than regular concrete blocks.

TROMBE WALLS: The Druk White Lotus School in Ladakh, India, used Trombe walls as a passive solar design that op-

FOR SUSTAINABLE STRUCTURAL ENGINEERING

timizes thermal performance. A Trombe wall consists of an external wall made of glass or plastic glazing panes and an internal wall with high heat capacity, with a small air gap separating the two walls. Sunlight heats the wall during the day. At night, as the wall cools, it heats the air in the gap that then circulates to the interior via vents. The system is perfect for Ladakh, since the region enjoys 320 sunny days a year. Before Trombe walls were used, traditional fuel, wood, and kerosene were used for heating, generating indoor air pollution that caused health problems.

ECO-LADRILLO BOTTLE BRICKS: The name eco-ladrillo is derived from the Spanish word for "brick." But instead of baked clay, the technique uses plastic bottles as a construction material. Bottle walls were used by the nonprofit Hug it Forward to help local communities in Guatemala build 12 schools for US$15,000 each. In the Dominican Republic, eco-ladrillos figured into a project organized by students from Humboldt State University and RevArk in 2011. The schoolroom, called the La Yuca Eco-Ladrillo, used eco-ladrillo walls made out of plastic bottles filled with renewable waste material, which were both accessible and locally available. The eco-ladrillo walls weigh less than traditional concrete walls, therefore they are less of a threat to safety if they collapse.

EARTH BAGS: Woven polypropylene bags filled with locally available inorganic material and moist subsoil, called earth bags, were used to build an education center in Nepal. The bags are designed to have internal stability and resilience against earthquakes due to their self-interlocking nature and the consolidation of the moist fill inside. The bags are also connected by barbed wire and mesh for friction and tension resistance to shifting.

Proof of the effectiveness of the technique is that, unlike many structures built from concrete blocks or bricks, the education center built with simple earth bags survived the devastating 2015 earthquake in Nepal. ME

YAN CHU is a structural engineer in Hong Kong. For more about development engineering, go to engineeringforchange.org.

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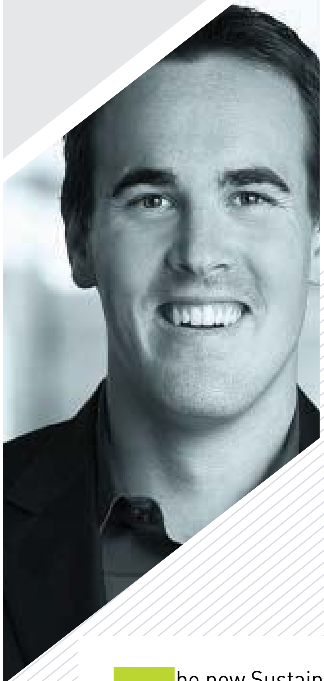

MEASURED IMPACT, NOT PROMISED INTENT

In spite of good intentions, **the fickle flow of funds for development engineering** creates incentives for new projects, **not the sustained delivery of services**.

The new Sustainable Development Goals in September 2015 were announced with fanfare by the United Nations. And the intent of the 17 goals—everything from "ensure access to water and sanitation for all" to "end poverty in all its forms everywhere"—were admirable. What was less apparent was how actual impact and success would be measured.

The same problem dogged the predecessor Millennium Development Goals, the eight objectives for 2015 that the U.N. established in 2000. The U.N. claims that many of the MDG targets were met, but the standards and measurements it used were often too weak or insufficient to justify those claims. The fear is that if the new Sustainable Development Goals proceed without measurable standards directly aligned with the intended impact, they too may fall short.

That's a trap a lot of development agencies run into. Recently, the United States Government Accountability Office released a report commending the United States Agency for International Development for its water and sanitation efforts. While highlighting that, the agency was likely overstating the impact of those efforts, even by USAID's own metrics.

For instance, USAID recommends using annual indicators such as "number of people gaining access to an improved drinking water source" in assessing programs. However, such indicators don't meaningfully address such important factors as measurable water quality, sanitation level, or health impact. And USAID failed in many cases to collect any data at all.

This isn't an indictment of USAID or the United Nations, but rather examples of the status quo in delivering well-intentioned environmental health interventions. The finite and fickle flow of funds incentivizes new projects, not the sustained delivery of services. And the lack of objective data on program performance contributes to a subsequent lack of accountability and misallocation of resources.

New tools and policy mechanisms may help. For instance, continuous feedback rather than annual data collection may spur communities to remain engaged with development agencies, which can then respond promptly to problems. That approach could not only raise quality and accountability. With access to monitored data on the appropriateness and success of pilot programs,it could also enable investors and the public to make better informed decisions on funding.

These issues were on my mind as I finished work on a book I edited, *Broken Pumps and Promises: Incentivizing Impact in Environmental Health*, published in March by Springer. My co-authors and I highlighted some of the challenges in the current models of global environment and health efforts, and offered case studies of how to leverage feedback mechanisms to prove—and improve—impact.

Case studies by authors from the Rockefeller Foundation, Yunus Social Business, and the World Bank explored feedback tools, including performance-based payments. For instance, the Freshwater Trust has leveraged clean water crediting for ecological restoration in the United States, and DelAgua Health uses carbon credits to provide public health interventions that improve water and air quality in Rwanda.

New technology tools, such as cellular sensors and mobile money payments, are being used by an Oxford University program to deliver water pump services in Kenya and by social enterprises including Nairobi-based Sanergy to deliver sanitation services. Similar tools are used to monitor—and monetize—the health impacts of improved cookstoves.

Kurt Vonnegut once wrote, "Another flaw in the human character is that everybody wants to build and nobody wants to do maintenance." That's certainly been the experience of many in global development. But with these innovations, perhaps this flaw in the global development model may soon be addressed. ME

EVAN THOMAS is an assistant professor of mechanical engineering at Portland State University, COO of DelAgua Health, and CEO of SweetSense, Inc.

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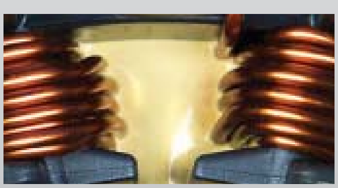

SILICONE-SENSITIVE APPLICATIONS

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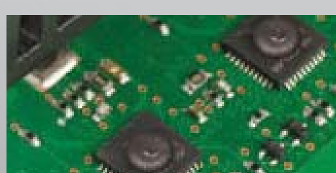

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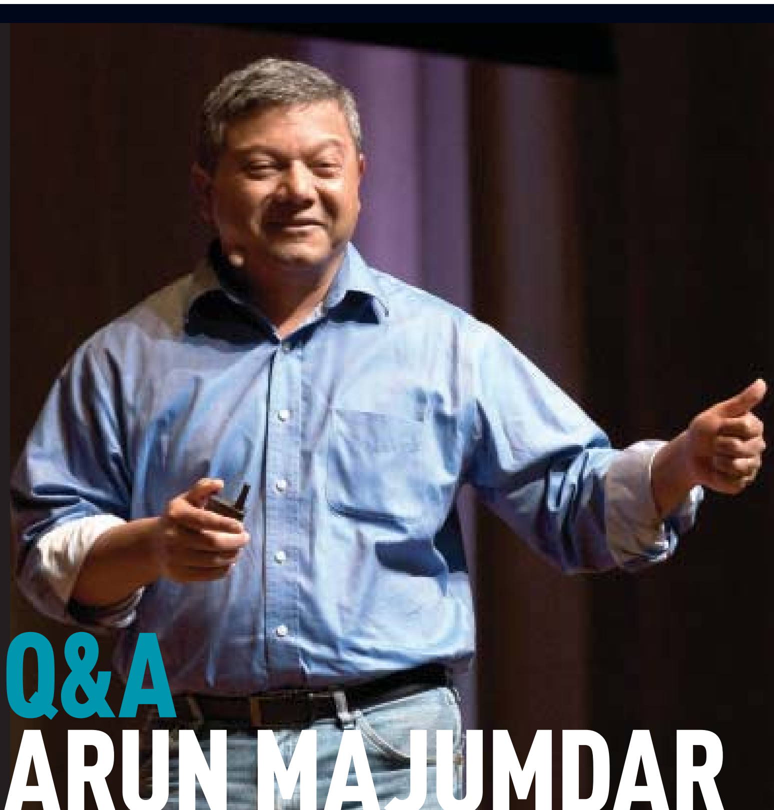

Q&A ARUN MAJUMDAR

FROM SCIENCE AT THE NANOSCALE to energy policy at the global scale, Arun Majumdar is a recognized thought leader. The one-time director of the Berkeley Nanoscience and Nanoengineering Institute became the founding director of the Advanced Research Projects Agency-Energy in 2009. He also served as senior advisor to the U.S. Secretary of Energy and spent a year as Acting Under Secretary of Energy. Majumdar is now a professor in Stanford's department of mechanical engineering and vice president of energy at Google. Here he talks about how to tackle the world's energy problems as well as achieving a cleaner future.

ME: Is there a single thread to your life story so far?

A.M: You don't plan for these things. I wanted to do research and teaching. Then things kind of happened. The goal was to make some positive impact through engineering and the sciences and it just so happened that the world of policy and politics came along.

ME: Do the policy and technological challenges that face us ever make you lose hope?

A.M: As a researcher, you're always optimistic—that's the definition of a researcher—because most of the things that you do in research never work out. So it goes without saying that I'm a perennial optimist in terms of what innovations and technology can do.

ME: What's been the single most frustrating hurdle to solving our energy problems?

A.M: If people are unwilling to accept that there is a carbon problem—that CO_2 emissions need to be reduced, that at least there is a risk involved, that if the scientists are correct there is a risk we face. If people are not willing to even accept that there is a risk, it's very hard to make progress.

ME: In the world of policy, what do you think is the crucial next step?

A.M: There has to be a price on carbon. I'd rather have a simple, revenue neutral carbon tax. That is, if you tax someone, we use the money for health care or something else, it actually goes back to the people and is not a way for the government to make money. Use that tool to level the playing field of the energy industry and bring in the extra cost of CO_2 into the system. That will create the market for innovations.

ME: Can the market be so easily tamed?

A.M: When the markets don't work they need to be tweaked. That's what a price on carbon will do. The market needs to respond to the social cost of carbon. Obviously, when it doesn't happen it's a bit frustrating, but we just have to keep at it. This is not a 100-meter sprint, this is a marathon.

ME: Is the future of clean energy dependent on new technology, or can we get there from here with the right policies?

A.M: Absolutely we need new technology. Show me a battery that will make an electric car cheaper than a gasoline-based car with the same range. Doesn't exist. You need technology. But technology alone won't do it—you need the right policy framework as well. You need innovations in finance, business, and technology, and you need all those innovations working coherently so they are all pulling each other in the right direction.

ME: What do you think when you look back at your time in government?

A.M: I wouldn't say it's anger or regret, but you want to do the most you can. Frankly, it's never a solo effort—who you surround yourself with I think is critically important. But I wish sometimes that I could have done a little bit more for the team.

ME: Has your research and policy work changed your personal life, like the kind of car you drive?

A.M: When I was driving quite a bit, I drove an electric vehicle, but not only because it was cleaner, it was actually cheaper. And in California you get to drive in the carpool lane, which is faster. Cleaner, cheaper, faster—you can't go wrong with that. **ME**

MICHAEL ABRAMS is a New York-based technology writer.

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BIG NUMBER

$3.032 Trillion

Gross value of final products by U.S. industry in April 2016

IN SPITE OF WHAT YOU MIGHT HEAR ON THE HUSTINGS, U.S. manufacturing has not disappeared. The Federal Reserve Board monitors industrial production and reports that U.S. industry in April produced consumer goods and business equipment worth $2.72 trillion, as measured in 2009 dollars, or $3.032 trillion after inflation. That's not the record (it was set in September 2007), but production has grown continuously since 2009.

SMART CARTS

AUTONOMOUS MOBILE ROBOTS ROLL INTO FACTORIES.

Robotic arms designed to work next to people are already invading factories. Autonomous robots could be next.

They may look something like the MIR100 robot from Denmark's Mobil Industrial Robots A/S. Designed to carry goods between factory workstations or hospital rooms, the robot spots obstacles and chooses new routes with no human intervention.

"Naturally, we were a little skeptical at first, because it has to move about among walking staff and forklifts with goods, but there have never been any collisions," said Reni Hannibaldsen, production manager at Scan A/S, a Danish manufacturer of wood stoves. His MIR100 makes 10 to 12 supply trips a day.

Mobile robots already deliver parts in factories, but most must stick to a route defined by magnetic strips embedded in the floor. Autonomous robots, essentially mobile bases, provide greater flexibility. Users customize them with shelves, drawers, conveyors, or even robotic arms.

The MIR100 is capable of finding its own way around the factory floor.

Hannibaldsen said Scan added a hitch to its MIR100, which now tows carts with up to 300 kg in parts—and backs them into a parking spot when done.

Mobil Industrial Robots has been selling the MIR100 in Europe for 18 months. About 30 percent have gone to hospitals, which use the robots to deliver drugs and medical supplies.

Large factories with high labor costs account for the rest. Scan, for example, runs a 100,000-square-foot facility. Elos Medtech Pinol, another early Danish user, has a 90,000-square-foot plant to make dental implants. In both factories, it takes two robots to replace one full-time worker.

"It makes no sense to have highly paid machinists running from one side of building to another to pick up tooling or deliver parts for the next stage of processing," said Ed Mullen, MIR's North American CEO. By contrast, a MIR100 sells for roughly $30,000.

Programming takes three steps using a web browser, tablet, or smartphone. First, users show MIR100 a building's layout, either by downloading CAD floor plans or walking it around so it can create its own map. Next, they tag important areas, such as machining centers, paint booths, or packing lines. Finally, they create missions, such as taking a machined part to the paint booth.

Once the MIR100 arrives, an operator loads or unloads the cargo and clicks the mission button to launch the next task.

MIR100 complies with EN 1525, a European standard for inherently safe autonomous robots. Its full instrumentation—dual lasers, gyroscope, and ultrasonic and height sensors—enables it not only to make good navigation decisions, but also to back up.

"We can reverse and safely back out of a blocked aisle without human assistance and still comply with safety guidelines," Mullen said.

"For 15 years, we've been automating assembly lines. Now we can start automating product flow between lines," he added. ME

ALAN BROWN

EASIER FUELING FOR NATURAL-GAS

Natural gas burns cleaner than gasoline, but natural-gas-powered cars and trucks are scarce on American roads. In part that's because refilling natural-gas tanks requires an expensive electrically powered compressor. Now a new self-powered, dual-purpose engine and gas compressor, built from a standard V8 pickup-truck engine, lets users fuel up affordably from a natural gas line—even when the electricity goes out.

In driving mode, the dual-purpose engine, developed by Onboard Dynamics, a Bend, Ore., startup, combusts fuel the ordinary way in all eight cylinders, propelling all eight pistons to turn the

This eight-cylinder natural-gas-burning engine (left) also works as a four-cylinder gas compressor.
Image: Onboard Dynamics

CHINESE AUTOMAKER INVESTS IN LITHIUM

BYD, THE SHENZHEN-BASED MAKER OF electric vehicles, signed a deal in June with the Qinghai Salt Lake Industry Group Co. Ltd. to take part in lithium mining in saline lakes in northwest China's Qinghai Province.

Under the agreement, the companies will partner to build a plant with annual output of 30,000 tonnes of lithium carbonate, a raw material for making lithium batteries. According to the Xinhua news service, the plant will take two to three years to complete.

The lakes, which lie in the Qaidam Basin on the Tibetan Plateau, have long been mined for their mineral salts. Qinghai Province hopes to establish a lithium-mining industry capable of producing 200,000 metric tons of lithium carbonate from the basin annually.

According to Xinhua, Wang Chuanfu, the president and founder of BYD, said that the growth in electric car sales has driven up the price of lithium carbonate from 40,000 yuan ($6,084) per metric ton to 150,000 yuan last year. ME

VEHICLES

crankshaft. The Onboard Dynamics team used the engine to propel a Ford F-250 pickup truck.

In compressor mode, however, only four of the eight cylinders perform combustion. That combustion powers the other four cylinders, which act as a gas compressor.

This works because new hardware in a custom head switches off the spark plug and fuel injector for each of the four of the compressor cylinders, which keeps them from burning fuel. The combustion cylinders still fire, however, which turns the crankshaft and moves the pistons in the compressor cylinders. Specially designed proprietary intake and exhaust valves allow the moving piston in each compressor cylinder to pull natural gas into the cylinder, then compress it, said Shaun Mayea, an Onboard Dynamics mechanical engineer working on the project.

Three of the four compressor cylinders together compress natural gas from the 5 psi pressures in an ordinary gas line to 100 psi. The other cylinder compresses it from 100 to 400 psi. An external air pump then pressurizes it from 400 psi to the 3,600 psi typically used to store compressed natural gas, Mayea said.

"We are leveraging the internal combustion engine to be an onboard compressor," said Onboard Dynamics CEO Rita Hanson.

Onboard Dynamics has also mounted the dual-purpose compressor on a small trailer, creating a mobile device that can refuel multiple vehicles.

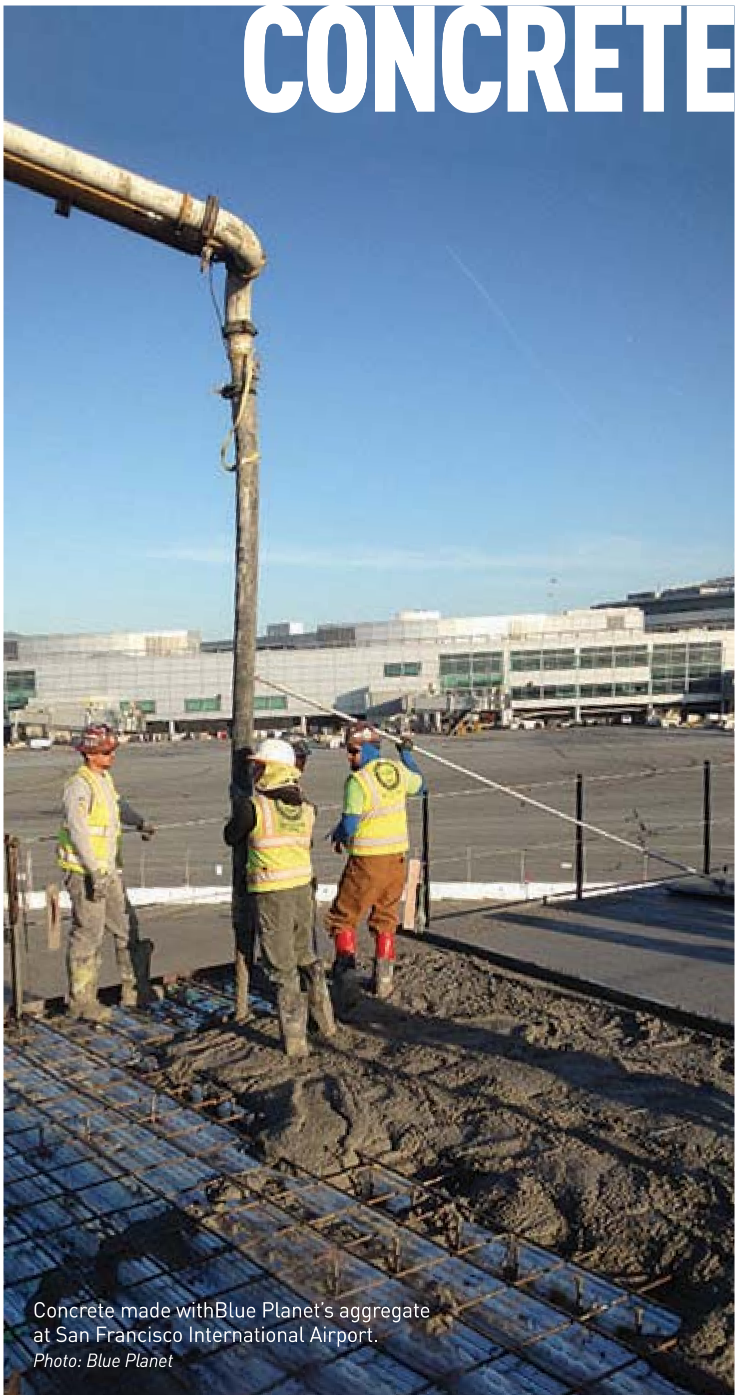
The company is fine-tuning the new compressor to be able to refill at least 10 vehicles with 20-gallon tanks per day, or the equivalent, Hanson said. In 2017, they plan to sell it to fuel commercial fleets of natural-gas vans and small trucks.

Eventually, they'd like to sell it to consumers. "To be able to take it to a consumer to be able to plug in their Honda Civic—that is the ultimate vision within my lifetime," Hanson said. "We are trying to break the barrier for adoption of natural gas." **ME**

"IF YOU LOOK AT THE ROBOTIC DEVICES that are coming into the restaurant industry—it's cheaper to buy a $35,000 robotic arm than it is to hire an employee who's inefficient making $15 an hour bagging French fries."

*— Former McDonald's USA CEO **Ed Rensi,** on the Fox Business Network, May 24, 2016.*

TURNING CO2 INTO CONCRETE



Concrete made withBlue Planet's aggregate at San Francisco International Airport. *Photo: Blue Planet*

AS COMPANIES LOOK TO LIMIT THEIR greenhouse gas emissions, carbon capture and sequestration has become an intriguing option. This month, we visit two labs seeking to turn that captured carbon dioxide into concrete, a building material that is also a major source of carbon emissions. One is already testing CO_2-based limestone aggregate, while the other is looking for ways to make limestone-like concrete from CO_2.

Blue Planet made the news early this year when it added actor Leonardo DiCaprio to a policy advisory board. In May, however, it celebrated a lower key but even more important event: The company, working with Central Concrete of San Jose, Calif., poured its first test patch of concrete using its CO_2-derived aggregate at San Francisco International Airport.

This is the just the first stage in Blue Planet's plans to turn CO_2 emissions into aggregate, sack concrete, reflective roofing, and white calcium carbonate pigments.

The company is currently building a pilot aggregate plant next to a natural gas power plant in Moss Landing, Calif., and planning another in Tampa, Fla., said CEO and founder Brent Constantz. In addition to heading Blue Planet, Constantz is a consulting associate professor at Stanford University and serial entrepreneur. He holds more than 100 patents on carbon capture and sequestration, and founded the carbon capture company Calera, which he sold in 2010.

Constantz is an expert in biomineralization, the process by which coral reefs and shellfish use carbon to form their mineral shells. In fact, Blue Planet creates aggregate in much the same way an oyster produces a pearl. "It's the same technology," Constantz said. "It's just like nature."

To produce aggregate, Blue Planet starts with CO_2

PAVING THE WAY

THE LAB Blue Planet, Los Gatos, Calif.; Brent Constantz, CEO.

OBJECTIVE Mimic natural biomineralization to economically convert carbon dioxide into concrete aggregate and roofing materials.

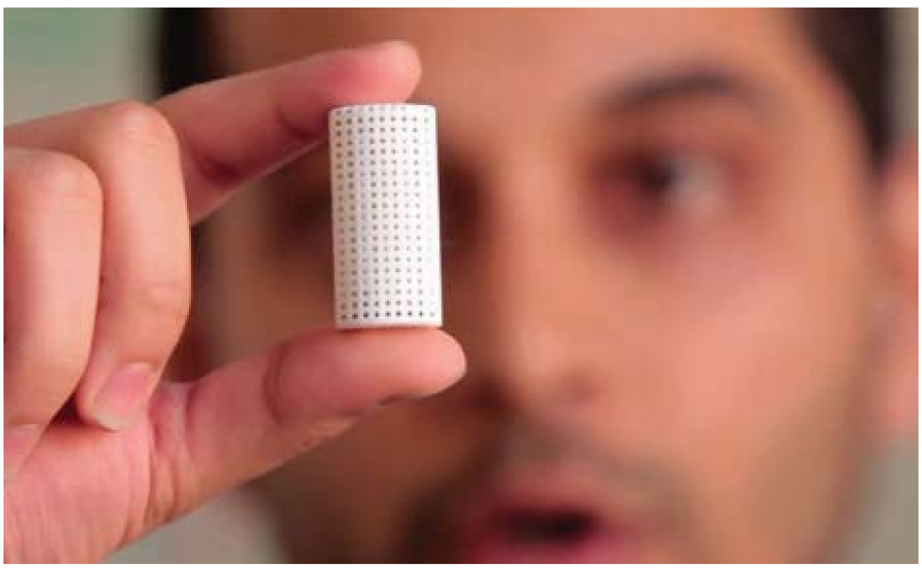
DEVELOPMENT First pour of a concrete test patch using an aggregate made from power plant CO_2.

flue gas and sand. It runs the gas through a reactor containing an ionized solution that absorbs 80 percent of the CO_2 to form a solution of liquid carbonate.

The system then pumps the carbonate solution into a slurry of sand and calcium-rich water. The carbonate and calcium ions react to form calcium carbonate ($CaCO_3$), or limestone, on the sand's surface. As the process continues, the limestone thickens layer by layer. Blue Planet lets the process proceed until the coating is half the weight of the sand. It takes Blue Planet about two hours to produce 1 ton of aggregate.

Constantz estimates it will cost $800,000 to build a 1 MW plant capable of producing 10,000 tons of aggregate per year. Shipping fees drive the cost of aggregate, he argues. By making concrete near CO_2-based aggregate plants instead of trucking aggregate from remote quarries, Constantz believes he can undercut the cost of conventional concrete.

"The whole process is economically and technically scalable," Constantz said. **ME**



A CLEANER CONCRETE

THE LAB Laboratory for the Chemistry of Construction Materials, University of California, Los Angeles; Gaurav Sant, director.

OBJECTIVE Develop sustainable, low-carbon dioxide cement and construction materials.

DEVELOPMENT Using carbon dioxide captured from limestone to create a new building material, CO2NCRETE, formed by 3-D printers.

3-D printed cones are the first step in creating building materials that could help to lower global greenhouse gas emissions.
Photo: UCLA

Gaurav Sant and his team are using 3-D printing to rewrite the history of cement and reduce carbon dioxide emissions by turning limestone into...limestone.

Limestone, used to build the Great Pyramids and the Parthenon, is strong and durable. Sant is developing a process to recycle CO_2 and 3-D print limestone, which he calls CO2NCRETE.

To understand why, consider cement, which acts as the glue to hold aggregate together in concrete. Producers make it by toasting crushed limestone at 750 °C, then mixing the resulting lime (CaO) with silicate-bearing sands at 1500 °C. Those two steps generate about 7 percent of the world's total CO_2 emissions.

Sant, an associate professor at UCLA's Department of Civil and Environmental Engineering, also begins by cooking limestone ($CaCO_3$) at 750 °C, but he captures the CO_2 driven off to use later in the process.

This produces lime, which he mixes with water to form a slurry of calcium hydroxide, $Ca(OH)_2$. Sant extrudes the slurry through a 3-D printer to form beams and other shapes. He then infiltrates the printed profiles with either liquid or supercritical CO_2 under pressure. This turns them into durable limestone CO2NCRETE.

"That was the most critical piece," Sant said about the process. "If that didn't work, nothing else would."

Processing limestone to make limestone may sound wasteful, but it has several advantages. For one, it is close to carbon-neutral. It can recycle at least 80 percent of the CO_2 from lime production and eliminates the silicate reaction (and its carbon emissions) entirely.

Second, it currently takes two hours to convert a 3-D profile to limestone, compared with 30 days for conventional Portland cements to harden fully. Finally, 3-D printing can support a wider range of practical building shapes.

The work is in its earliest stages, and the lab has challenges ahead. Those include optimizing slurry texture to keep it from clogging the printer heads or running too thin; finding effective binders to hold the slurry together; creating denser, stronger finished materials; and developing a more efficient membrane to capture purer carbon dioxide from flue gases.

"It's very much a work in progress," said Sant. **ME**

JEFF O'HEIR

GM TESTS NANOTECH STEEL

General Motors has begun testing its first shipment of an advanced steel that can be stamped using existing equipment to create strong, lightweight parts. The material was developed by NanoSteel of Providence, R.I., and manufactured by its partner, AK Steel, a $6.7 billion steelmaker that specializes in automotive steels.

Like the rest of the U.S. auto industry, GM is looking for ways to meet federal fuel economy standards, which are scheduled to rise to 54.5 mpg by 2025. If automakers want to continue making large pickups and sport utility vehicles, which are their most profitable products, they must find new—and economical—ways to eliminate weight.

In 2014, for example, Ford Motor switched to an aluminum body for its large F-150 pickup truck and shaved 700 pounds of the vehicle's weight. The change cost Ford hundreds of millions of dollars in plant renovations. Ford needed new presses to hydroform thick sheets of aluminum. It also had to replace robots that made 5,000 spot welds with machinery that applied self-piercing rivets as well as flow-drill screws and structural adhesives.

Other companies have opted for high performance steel. Ford did, too. It saved 60 pounds by building the F-150's chassis from advanced high-strength steel.

NanoSteel also makes an advanced high-strength steel, but the metallurgy of its product (also called NanoSteel) differs significantly from that of other alloys. Conventional steel is composed of small, island-like crystalline structures called grains—the smaller the grains, the stronger the metal. Unfortunately, heating and processing makes grains grow. Alloying steel with trace elements can limit that growth, but it makes the metal brittle.

Just the opposite happens in NanoSteel. As the metal reaches 85 to 95 percent of its melting point, the grain structure grows finer. This makes NanoSteel exceptionally strong (up to 1,200 MPa tensile strength) without sacrificing ductility (up to 50 percent elongation).

Thanks to its outstanding ductility, automakers can stamp and form parts at room temperature without investing in additional manufacturing equipment or employee retraining, said David Paratore, CEO and president of NanoSteel.

In addition, Paratore said that the material is potentially low cost because NanoSteel's partner, AK Steel, makes it from conventional alloying elements using standard slab casting equipment. ME

NOT EXACTLY BULLET TRAINS

It's known that trains take advantage of the low rolling resistance of steel wheels over steel rails to be more energy efficient than other forms of land transportation. But no rail vehicle has ever reported the efficiency that a team of engineering and industrial economics students from Dalarna University in Falun, Sweden, accomplished in May. The students built a passenger rail vehicle to enter in the annual Delsbo Electric Battery Powered Rail Vehicle Challenge, which sets student-built rail cars on a two-mile length of track to see which one can reach the end using the least amount of energy. Organizers liken it to the Shell Eco Marathon. The five-person Dalarna vehicle consumed only 0.84 Wh of electricity per passenger km. That's the equivalent of traveling more than 4 miles on a single D cell battery.

The average speed, however, was only around 3 mph. ME

THE HYPERLOOP RACE HEATS UP

The race to realize the Hyperloop—a new transportation concept that could propel passenger pods through extended tubes near the speed of sound—heated up in May.

On May 9, Hyperloop Transportation Technologies (HTT) unveiled the technology that will levitate passenger pods off rails and propel them inside a large tube.

On May 10, a rival company, Hyperloop Technologies, announced $80 million in new series B financing from heavy hitters in the technology investment space, including Khosla Ventures, GE Ventures, and the French high-speed rail company SNCF. That day the company also changed its name to Hyperloop One.

On May 11, Hyperloop One demonstrated its propulsion system, sending a 10-foot sled at 116 mph down an open-air test track it built in North Las Vegas, Nevada. The sled stopped by crashing into a pile of sand since its braking system has not yet been invented.

In a 2013 paper, Elon Musk, the billionaire founder of Tesla, the electric-car company, and Space-X, the commercial space flight firm, proposed transporting people and goods inside a pod moving at 760 mph, just shy of the speed of sound, while levitating off a track inside an evacuated tube. At that speed, a journey from Los Angeles to San Francisco would take 30 minutes.

HTT's levitation technology levitates capsules with permanent magnets, and it uses an electric motor and magnetic field to propel the pod. A regenerative braking system akin to that on a Toyota Prius would slow the speeding pod and regenerate almost all the electricity used to transport the pod along the track, thereby slashing energy costs.

Hyperloop technology differs from maglev, a type of levitating high-speed train that's already operating in China and Japan. Maglev trains need copper coils along the track and a lot of power, which make it an expensive form of public transportation.

Hyperloop One is building a two-mile tube for trial runs of entire pods by the end of the year, and Hyperloop One is building a five-mile test track for HTT in Quay Valley, California.

Observers of the technology have been skeptical that a working system could be built affordably, but HTT's chief operating officer, Bibop Gresta, claimed in a press release that by 2019 the company will transport its first passenger in a full-scale hyperloop. ME

THE ENGINEERING SCENE

LOOKING BACK

The model for American engineering education was under scrutiny when this article appeared in 1926.

WILLIAM E. WICKENDEN, DIRECTOR OF INVESTIGATION,
SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION, NEW YORK, N.Y.

An executive with the precursor to the American Society for Engineering Education compares engineering education in the United States to that in Europe, and finds ours wanting.

By way of summary and conclusion, let us recapitulate some of the more striking contrasts between higher technical education here and abroad.

• We have an unbalanced and top-heavy system, the result of imitation and the absence of any coordinating control comparable to the European ministries of education.

• Because our system is top-heavy, a good deal of it is pretentious. An insatiate craving for prestige, even though it may be hollow, and uncritical emotionalism characterize too much of our entire scheme of higher education. In comparison, European educators are realists.

• We have little to learn abroad as to material equipment, except in a few special laboratories in Germany. We might learn, however, how far short we fall of getting the full possibilities out of our investment.

• We have to compensate for the results of a scheme of secondary education which, however admirable in its widely inclusive democracy, is comparatively flabby and superficial. In point of mental maturity and discipline, extent of knowledge, and capacity for hard work, the European youth of eighteen is nearly two years in advance of our own. By intensive methods and a crowded schedule we recover about half the deficit in our four-year programs and send our graduates out on an approximate par with the product of a three-year program in Great Britain, somewhat behind the product of the best three-year programs in France, and practically a year behind the diploma engineer from the four-year programs of Germany, Austria, Switzerland, Holland, and the Scandinavian countries.

• We shall lag in the higher stages of technical education unless we can get our abler students to assume much more initiative. Our whole set-up tends to become a scheme to give students an education. Too often our colleges are highly elaborate schoolhouses, our students are overgrown schoolboys, and our professors glorified schoolmasters. The take-it-or-leave-it program abroad assumes that students are expected to get themselves an education, under the guidance of creative men and in an environment of real intellectual production.

In conclusion, I find myself drawn to the conviction that we have a program of technical education which is well suited to a considerable group of our students of a medium grade of ability. The present program is plainly too long and too complex for a large group of lower powers. But there is a third group, not large and probably not as large as it should be: Young men of high native ability and mental energy. We need a better program, a freer program, for these men, and in providing for them we have most to learn from our colleagues across the Atlantic. **ME**

BIRTH OF ROCKETRY

When William Wickenden worked in engineering education, it was hard to ignore examples of European technological superiority. But earlier that year, a Massachusetts-based physicist and engineer demonstrated a technology that would change America—and the world. Robert H. Goddard successfully launched the first liquid-fueled rocket from a field in Auburn, Mass., on March 16, 1926. That first flight rose only 41 feet and ended in a cabbage field, and for the next 30 years, Europeans had greater success than Americans in developing the technology. But spurred by the Soviet launch of its *Sputnik 1* satellite in 1957, the American government eventually poured resources into rocketry—and into science and engineering education, too.

Rocketry pioneer Robert H. Goddard with his first liquid-fueled rocket, March 16, 1926.

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3	Combustion Turbines	19	NEW: Plant Construction Issues and Supply Chain Management
4	Boilers & Heat Recovery Steam Generators	20	Commercial Applications of Energy Storage
5	Nuclear Steam Supply Systems Including Advanced and Small Modular Reactors	21	Batteries and Electrochemical Energy Storage
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		33	Posters

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Presentation-only abstract deadline: March 13, 2017

***There will be NO extensions to the publications schedule for the 2017 program.* Authors should submit a 400-word text-only abstract. Please visit the website for a description of the paper types and submission options.

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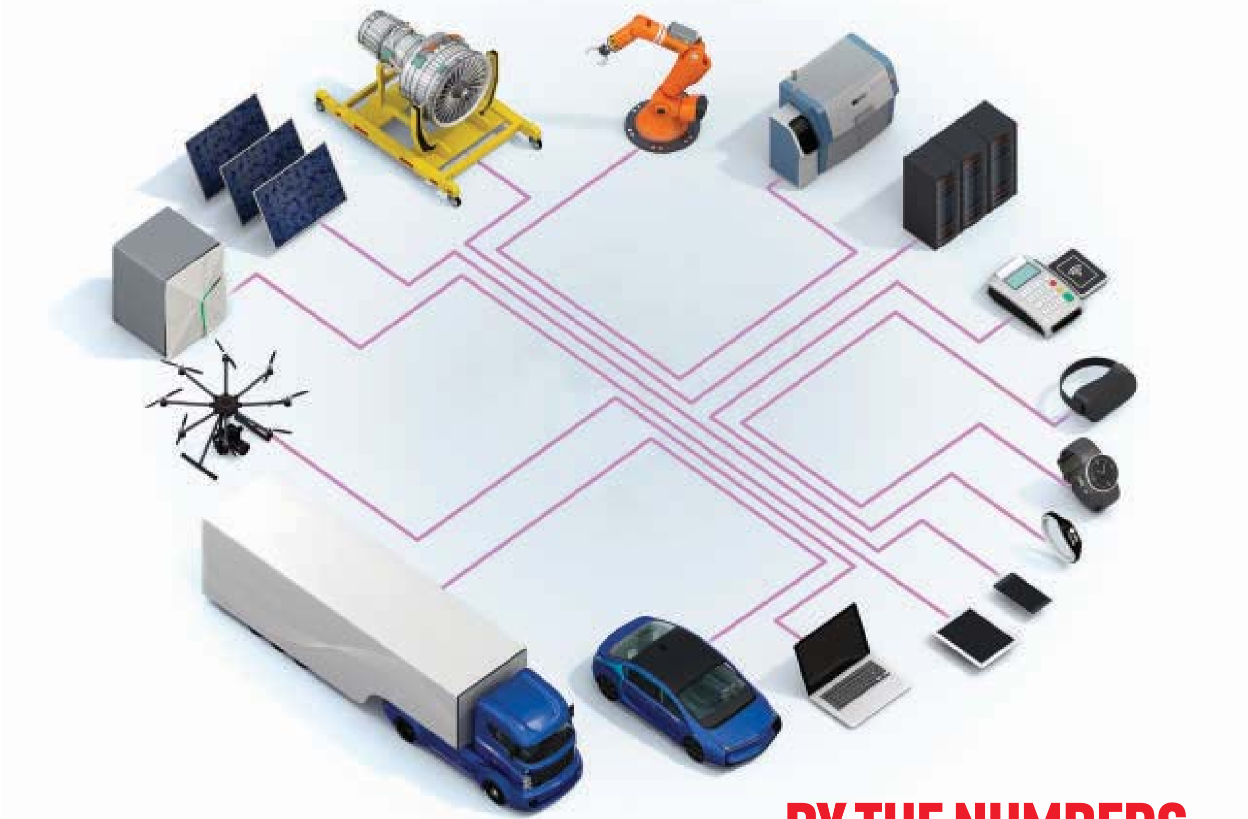


BY THE NUMBERS:

THE IIoT IS ON THE WAY ... AND HERE TODAY

PROCESS AUTOMATION—INDUSTRY OUTLOOK

Frost and Sullivan reports automation growth in the electric power industry is driven by energy demand in developing countries.

PROCESS AUTOMATION SEGMENT: GLOBAL REVENUE (IN BILLIONS OF DOLLARS) BY END-USER INDUSTRY

	Oil & Gas	Electric Power	Chemical & Petrochemicals	Metals & Mining	Life Science	Food & Beverage	Water & Wastewater	Others
2014 ($B)	7.99	9.07	4.61	3.17	1.85	4.20	2.17	5.32
Growth (%)	*1.8*	*2.5*	*2.2*	*0.9*	*2.2*	*1.2*	*0.5*	*-0.2*
2015 ($B)	8.13	9.30	4.71	3.20	1.89	4.25	2.18	5.31
Growth (%)	*3.0*	*5.1*	*5.5*	*4.4*	*4.8*	*4.7*	*4.1*	*2.6*
2016 ($B)	8.37	9.77	4.97	3.34	1.98	4.45	2.27	5.45

Other report highlights:

- Lower oil prices continue to affect upstream petroleum projects. The industrial automation business will see a revenue loss against expections of about $300 million in 2016.
- Process automation technologies are penetrating the food and life sciences industries with scalable architecture for batch management along with quality control functionalities.

There's likely no hotter concept than the Industrial Internet of Things, which promises to embed network-connected sensors and control systems in both production machinery and products. To futurists, the possibilities inherent in the IIoT are endless. But while industry has yet to fully game out what to do with that impending flood of data, technologies that make use of network connections to automate industrial tasks are increasingly being adopted across many fields.

Earlier this year, the consulting firm Frost and Sullivan reported on trends in industrial automation. The company projects that the global automation industry will reach nearly $56 billion in revenue this year, up 4.5 percent over 2015.

The company looked at recent and projected growth in automation aimed at both process industries, such as petrochemical refining or wastewater treatment, and the so-called discrete industries, such as automobile manufacturing or aerospace. According to the Frost and Sullivan report, *2016 Outlook of the Global Automation Industry: Industrial Internet of Things (IIoT) Technologies and Innovative Service Model Will Lead Market Growth*, process industries currently are the biggest destinations for industrial automation technology. Of the top five industry markets for automation technologies, four—electric power, oil and gas, chemical and petrochemical, and food and beverage—are process industries. (The fourth largest industrial market is machinery.)

"The automation market in the electric power industry is likely to be the most promising in 2016 and beyond," Frost and Sullivan reported, "due to large greenfield projects in the emerging markets of India, China, and Southeast Asia. In addition, growing projects in renewable energy in Europe would boost demand for automation in the region." All told, the global electric power industry is projected to purchase $9.77 billion in automation technology products and services this year, an increase of more than 5 percent over 2015.

The report also looked at the mix of technologies being purchased. Distributed control systems for process industry applications were the biggest market segment, with more than $15 billion in sales, but it was also the segment with the slowest growth. By contrast, the market for variable frequency drives was projected to be $11.7 billion in 2016, up more than 12 percent since 2014, thanks to the need to meet energy efficiency requirements in the Asia-Pacific region. Programmable logic controllers, most of which are destined for process industries, account for another $12 billion.

It is expected that the influence of this automation technology will only grow going forward. Frost and Sullivan predicted, "An increasing number of successful pilot projects are likely to opt for more commercialization of smart sensors, intelligent machines, and advanced automation technologies, driven by Industry 4.0 and smart manufacturing initiatives."

While the futurists wax eloquently about the Industrial Internet of Things, many of its pieces are already in place. ME

JEFFREY WINTERS

2016 AUTOMATION REVENUE

Technologies	Process Industries	Discrete Industries
Distributed Control Systems	$15.6 billion	--
Programmable Logic Controllers	$8.4 billion	$3.8 billion
Supervisory Control and Data Acquisition	$5.1 billion	--
Process Safety Technologies	$2.5 billion	--
Human Machine Interface	$1.8 billion	$1.4 billion
Variable Frequency Drives	$6.9 billion	$4.9 billion
Generic Motion Control	--	$3.4 billion
Machine Safety	--	$1.9 billion

Data: Frost and Sullivan

DISCRETE AUTOMATION—INDUSTRY OUTLOOK

The demand for automation technology from the electronics and machinery sectors is booming.

DISCRETE AUTOMATION SEGMENT: GLOBAL REVENUE (IN BILLIONS OF DOLLARS) BY END-USER INDUSTRY

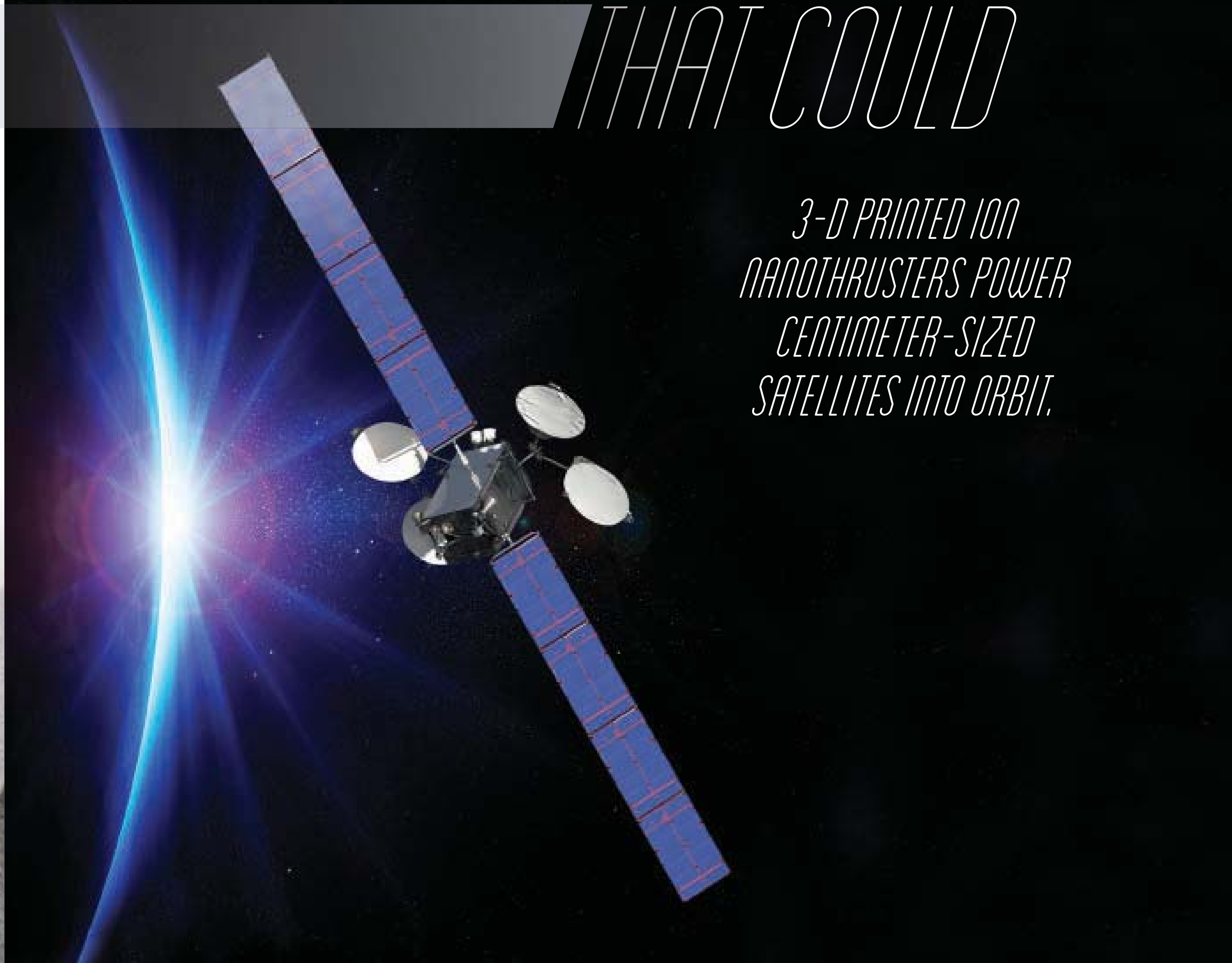
	Automotive	Machinery	Semiconductors & Electronics	Aerospace & Defense	Others
2014 ($B)	3.65	4.61	2.03	0.80	2.83
Growth (%)	*5.2*	*4.1*	*5.4*	*5.0*	*3.5*
2015 ($B)	3.84	4.80	2.14	0.84	2.93
Growth (%)	*5.7*	*5.8*	*6.1*	*4.8*	*4.1*
2016 ($B)	4.06	5.08	2.27	0.88	3.05

Other report highlights:

- Machinery industry growth is largely driven by rising demand from developing countries because the market is becoming mature and saturated in Europe and North America.
- Growth in the aerospace and defense industry is driven by improving project performance and adoption of smart technologies.

THE LITTLE ROCKET ENGINE THAT COULD

3-D PRINTED ION NANOTHRUSTERS POWER CENTIMETER-SIZED SATELLITES INTO ORBIT.



BY GREG FREIHERR

CubeSats are space age hitchhikers, miniature spacecraft that fly into orbit aboard rockets whose primary payloads are full-size satellites. Measuring about 10 centimeters on each side and weighing less than 1.5 kilograms, CubeSats often ride for free. And, like their human counterparts on Earth, they are often dropped off short of where they want to go.

Because beggars can't be choosers, CubeSats—which could perform tasks as varied as monitoring disasters and repairing orbiting structures—must use their own propulsion systems to get to their destinations; to make the adjustments needed to stay there or go to another location; or even to reach escape velocity and travel to interplanetary space.

Paulo Lozano and his team at MIT's Space Propulsion Lab have developed a unique kind of rocket engine for these microsatellites. Dubbed the ion electrospray propulsion system, the electric engine fires tiny streams of ions that push these mini-spacecraft into desired orbits and keep them there.

Using semiconductor manufacturing technology, Lozano's team creates chip-sized thruster modules that measure only 10 x 10 x 2.5 mm and could comfortably fit on a dime. An engine that controls yaw or pitch might use four modules, while a main propulsion engine would house many more, depending on the amount of thrust required.

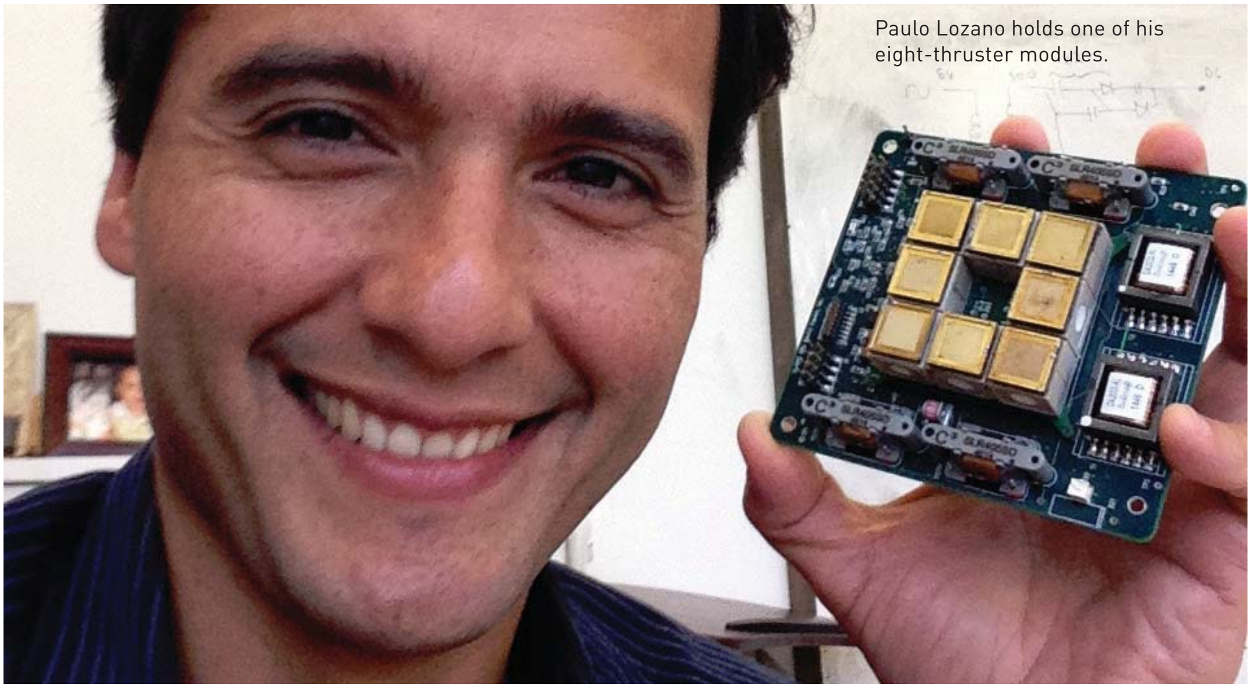
The thruster modules themselves consist of an array of hundreds of small volcano-like cones called emitters. Instead of burning chemical fuels, they accelerate ions out of openings so small, their diameters are measured in nanometers and their thrust in nanonewtons.

"If you take a mosquito, cut off its antenna and divide it into maybe 50 sections—one of those sections would be a nanonewton in weight," Lozano said.

Because a pound of thrust translates into 4.8 billion nanonewtons, it would take about a million billion ion engines to produce the thrust of just one of the five rocket engines on the first stage of the Saturn V moon rocket.

Yet, given enough modules firing over a long

Eight chip-sized thruster modules, each only 10 x 10 x 2.5 mm, are mounted on a printed circuit.



Paulo Lozano holds one of his eight-thruster modules.

enough time, an ion engine will vault a CubeSat from a low earth orbit (2,000 km or lower) into a 36,000 km geosynchronous orbit, or even beyond the clutches of Earth's gravitation and onto the moon or other planets. It can do it with only 150 g of fuel and still leave 70-90 percent of the CubeSat free for critical sensors and electronics.

No other propulsion system comes close.

THE ANTI-ROCKET

For conventional space rockets to escape Earth's gravity, they have to generate a lot of thrust and burn a lot of fuel. A rocket that relies on chemical combustion must carry 20 to 40 times more fuel than the weight of the payload. Starting from a launchpad, it will burn through that fuel in minutes to reach escape velocity, just over 40,000 km per hour.

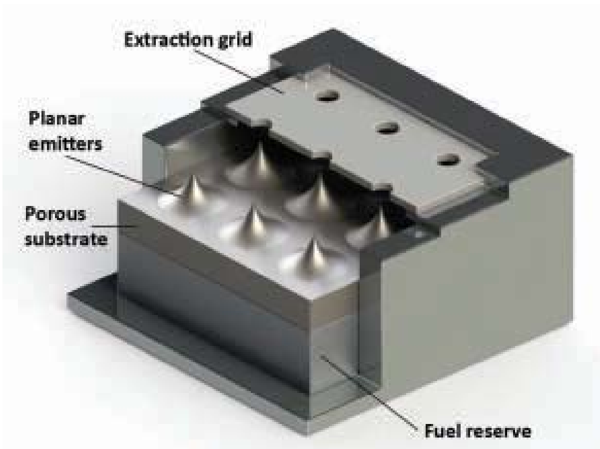
Lozano developed his electrospray engines for spacecraft that are already in orbit and that no longer have to do that type of heavy lifting. They can travel and maneuver with far less thrust.

In fact, ion engines use fuel so parsimoniously that they can fire for prolonged periods, shut down, and then fire repeatedly without fully depleting their reserves. The thrusters accelerate ions to many times the velocity of a chemical rocket's exhaust, producing more thrust than might be expected from such a small stream of ions. As long as time is not an object, firing long bursts of high-speed ions provides all the thrust needed to accelerate CubeSats into higher orbits and beyond.

While rocket scientists typically describe engines as "firing," this is misleading. "Firing" is to ion propulsion what "filming" is to digital videos. Electrospray engines do not ignite. They have neither the bell-shaped nozzle that characterizes rocket engines, nor the valves, regulators, and pumps.

Instead, ion engines use passive capillary action to wick propellant—an ionic liquid such as a salt solution—from a plastic holding tank through a porous substrate and up to the cone emitters. There are no moving parts. Since ionic liquids already contain ions, there is no need for a reaction chamber to ionize particles.

The cone-shaped emitters accelerate ions through an electrical field generated by the CubeSat's batteries, which are recharged by solar panels. It takes a mere 5 W of electricity—at voltages up 1,000 V—to produce a field at the top of the thruster module's emitters, where the propellant rushes to meet the vacuum of space.



The trick to building a successful ion electrospray propulsion system, Lozano explained, is to increase thrust density by jamming together as many emitters as possible. A single 1x1 cm module may contain 400 or more emitters. Add enough modules to a 10 cm x 10 cm CubeSat surface and total thrust approaches the millinewton range.

"They produce little force, but because they can fire for a long time, you accelerate the spacecraft to a velocity that would be impossible to get with a chemical engine," Lozano says. "That is a big value."

Electrospray engines also differ greatly from another form of ion propulsion, plasma ion, which also eschew chemical combustion for the efficiency of the electron. Plasma engines have repositioned Boeing satellites already in geosynchronous orbit since the 1990s. Last year, for the first time, they pushed two Boeing satellites from low Earth to geosynchronous orbits.

Like ion electrospray engines, plasma engines fire for long periods of time. While they take up less room than chemical rockets, which are 90 percent propellant by weight, plasma engines are still bulky. To start with, they require fuel tanks of compressed fuel, usually an inert gas. Xenon is a popular choice because it compresses well for storage, ionizes easily, and has high mass that produces more thrust than would a lighter atom when accelerated.

A regulator metes the gas through pipes and into a reaction chamber. There, a discharge cathode injects high energy electrons into the gas, producing a plasma. An electromagnetic field contains the plasma, which is then accelerated through an electrically charged grid at very high speeds.

It takes power to operate the discharge cathode, magnetic containment, and acceleration grid. Boeing's electric satellites operate at 3 to 9 kW, compared to 5 W for Lozano's ion electrospray system.

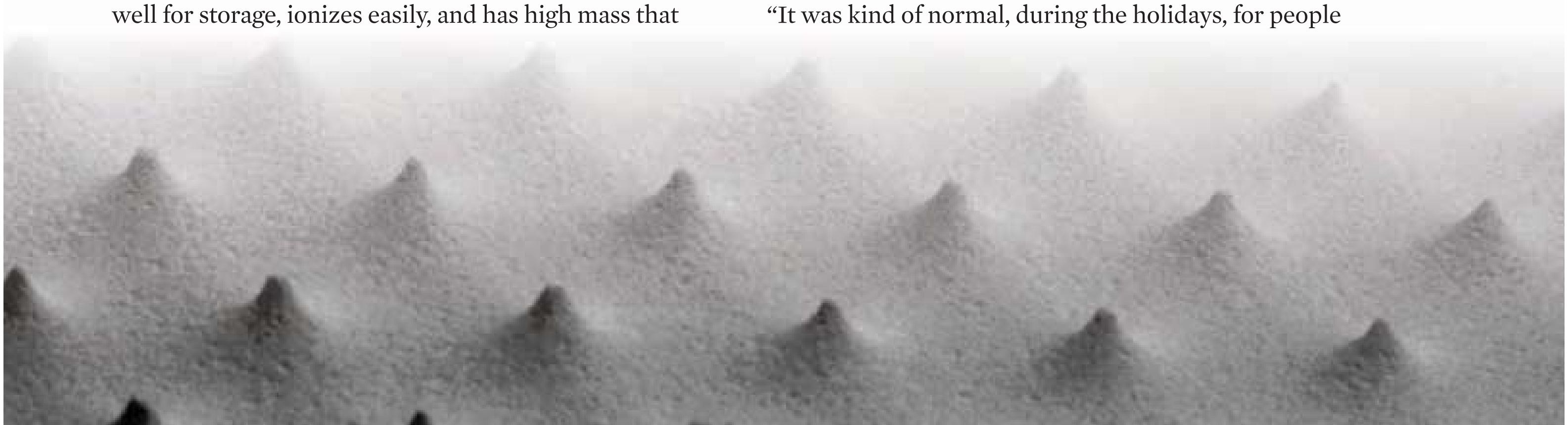
"You have thrust that is about an order of magnitude higher than what we have now. If you wanted to substitute that thruster for ours, you would need an area about 10 times larger," Lozano said.

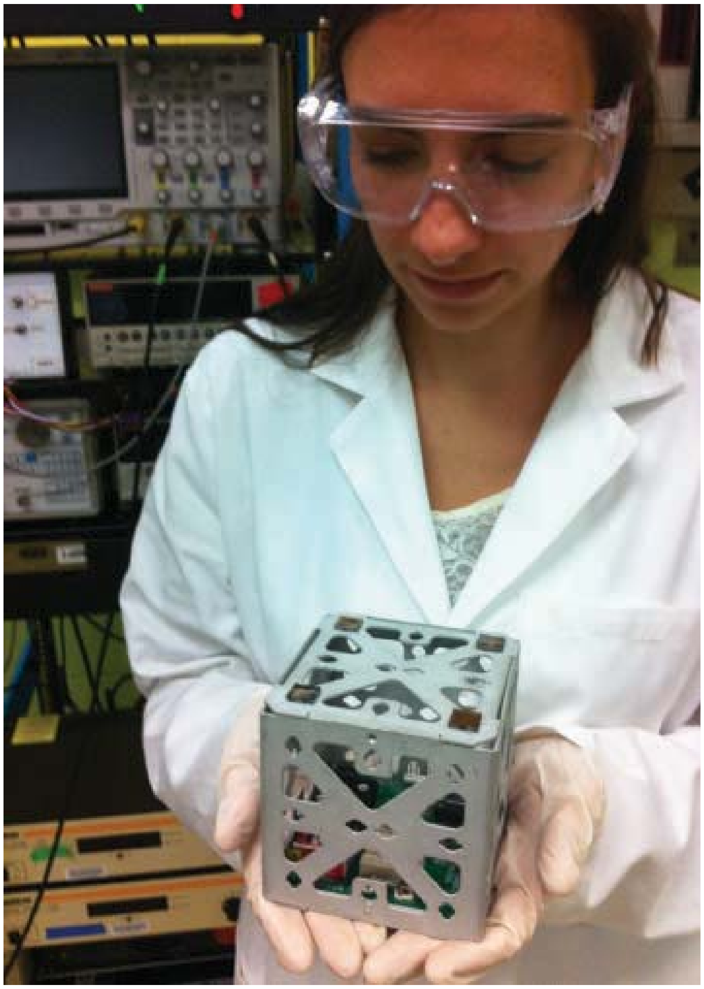
At first, Lozano tried to miniaturize plasma engines to fit CubeSats, but they were too complex to fit into their 1,000 cubic centimeter volume. He turned to ion electrospray engines as an alternative. Without valves, pipes, pumps, and pressurized tanks, they are to conventional and plasma electric rockets what thin LED displays are to cathode ray tube TVs.

MISSIONS

In some ways, Lozano's transition to ion engines mirrored his own journey from gunpowder to electricity and then space travel as a child in Mexico City.

"It was kind of normal, during the holidays, for people





Natalya Brikner, CEO of Accion Systems, holding a CubeSat. Her company seeks to commercialize ion electrospray propulsion.

to set off fireworks all the time," he said. "We would get their gunpowder for our own explosives. We blew up a lot of stuff."

But as Lozano, now a MIT associate professor of aeronautics and astronautics, grew older, he was drawn more towards electricity than explosions, spending time in bookstores because public libraries in Mexico City were scarce. While electromagnetism might seem safer, it too had its hazards. "I got shocked many times," he recalled.

He also fell in love with space travel, thanks in large part to *Star Trek*, *Star Wars*, and *Battlestar Galactica*.

"In all the science-fiction movies and television programs, for me the most exciting part was always the engines—*Star Wars*'s TIE and X-Wing fighters—and how they were able to move around so quickly," he said.

It's not surprising that Lozano merged his love for electricity with his interest in rocket engines. After all, the "TIE" in TIE fighters stood for "Twin Ion Engines." Building the ion drive, Lozano said, "has fulfilled one of my dreams."

While no one is going to confuse a CubeSat with a TIE fighter, the tiny satellites are surprisingly versatile. This is because ion engines can drive and reposition CubeSats during long missions and still leave lots of room for electronics and even mechanical devices.

Developers hope to take advantage of this flexibility. They are contemplating missions that range from removing debris and nonfunctioning satellites from orbit to nudging existing satellites onto new flight paths. CubeSats, working alone or in groups, could become the maintenance staff of space, inspecting, docking, assembling, and repairing orbiting structures. They could even be used to explore interplanetary space.

Last year Lozano and his team of a dozen post-docs, graduate students, and undergraduates, sent three of their engines to NASA for evaluation. Engineers at NASA Glenn Research Center in Cleveland, Ohio, are now putting the engines through their paces to understand their behavior.

"Electrospray thrusters are very new. But more and more people are realizing that they may be the way to go in electric propulsion, because they have so many advantages," Lozano said.

A big advantage, when asking for permission to hitchhike a ride into orbit, is that ion electrospray propulsion engines cannot explode and destroy a rocket's primary payload.

"By definition, chemical thrusters can blow up and people don't want to put a $500 million satellite in danger," Lozano says.

Even plasma engines are vulnerable because they store gaseous fuel under high pressure. Ion engines, on the other hand, do not contain combustible materials, pressurized containers, or even moving parts. Unlike the firecrackers of Lozano's childhood, they are very, very safe.

"If you can demonstrate that what you have cannot blow up, then people are happy with you," he said.

SCALING UP

A second advantage of ion engines is their modularity and, consequently, scalability. Need more thrust? Just add more modules, Lozano said. A small CubeSat, for example, might host four thrusters to handle attitude control and main propulsion. A larger CubeSat might need 16 for these functions. The only limitation is the surface area on which the modules can be mounted.

Even then, engineers could design satellites to provide more area, if needed. They could, perhaps, add thrusters to pop-out structures that deploy like solar panels once in orbit.

Another approach, which Lozano and his team are investigating, is to find better propellants.

"There are hundreds and thousands of possible propellants described in the literature, so it is very unlikely that we are using the optimal one," he said.

While CubeSats are a near-term opportunity, Lozano aspires to greater things. Ultimately, he hopes to make ion engines powerful enough to propel full sized satellites that weigh thousands of kilograms.

"We are about an order of magnitude lower in thrust density compared to the plasma thrusters that put the Boeing satellites into their orbits," Lozano said.

A big obstacle to powering such large objects is doing the one thing that ion electrospray engines cannot do: Get satellites moving quickly. Conventional chemical engines can boost navigational and communication satellites from low earth to geosynchronous orbits in a few days of repeat burns. Lozano's ion thrusters would need weeks, even months, to make the transition.

Still, that might not be such a bad thing, considering the weight savings possible with ion engines and the long lifespan of these spacecraft, Lozano said.

"After all, the satellites are going to survive for 15 years or so. Their owners really aren't going to care if they can't invoice their use for the first three months," he said.

Lozano is working with a spinoff company, Accion Systems (Accion is short for "accelerated ion"), to commercialize ion engines. The company's executives are mostly youthful space propulsion specialists. In addition to Lozano, the advisory board includes Steve Isakowitz, the president of Virgin Galactic, and Bill Swanson, the former chairman and CEO of Raytheon.

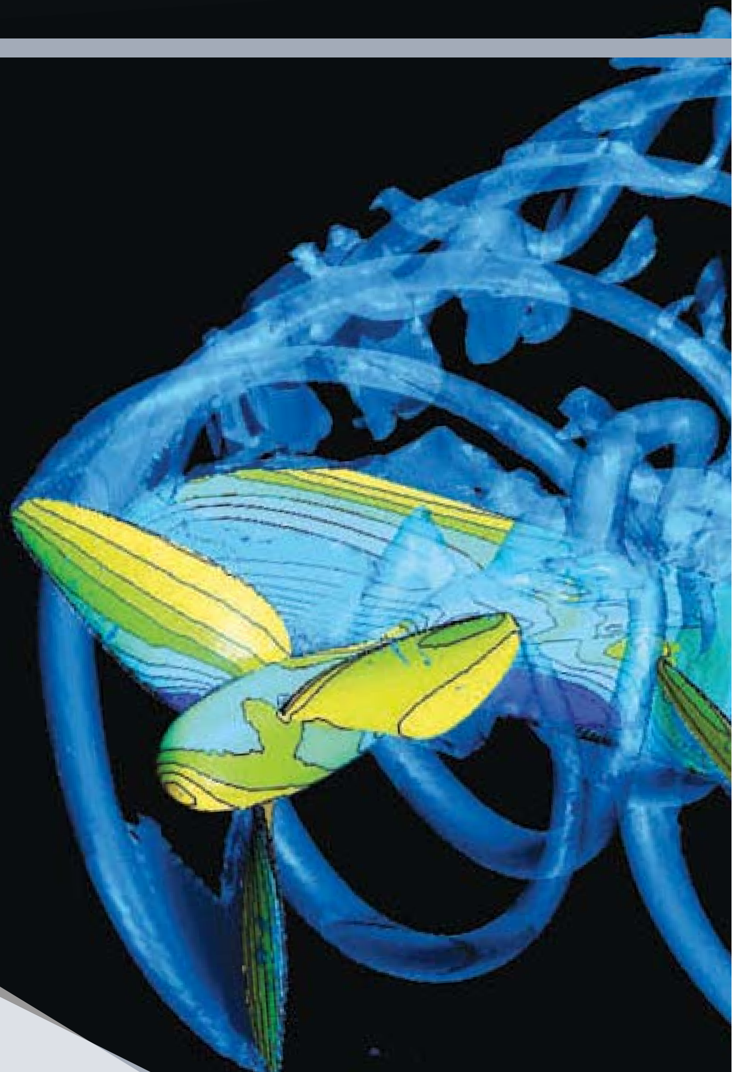
In 2015, Accion signed a $3 million Department of Defense research contract, cashed its first commercial checks, and won a *Fortune* magazine contest by convincing judges it could eventually grow into a $1 billion company.

More to the point, Accion is readying hardware that is scheduled to fly one mission this year and a second in 2017. Next year's mission features a larger ion engine that could take a CubeSat beyond the pull of Earth's gravity.

While Lozano is notably reticent about mission details and what entity is underwriting them, he says that the flight, if successful, will demonstrate the ability of ion engines to send CubeSats "on escape trajectories and interplanetary maneuvers." He also confirms that the target of the 2017 mission is the moon, noting that "we're not going try to land on it—but we might hit it."

Which is certainly a long way for a hitchhiker to travel. **ME**

GREG FREIHERR is a Wisconsin-based technology writer.



Propeller Innovation Takes Off

BY JEFF O'HEIR

For the first time in a century, propeller design is undergoing a revolution.

Aerospace engineer Jeremy Bain took one look at NASA's experimental propeller and wing designs and thought there was absolutely no way they could ever work.

Bain, who runs Bain Aero in Stockbridge, Ga., is known for his expertise in analyzing rotors and propellers using computational fluid dynamics. Two years ago engineers working on the Leading Edge Asynchronous Propellers Technology, or LEAPTech, project reached out to Bain to show him some very early wing designs they were working on.

What they presented looked like nothing else in aviation. Eighteen small electric propellers were distributed along the leading edge of thin wings with just a 31-foot wing span and an area a third of those on an average commuter plane.

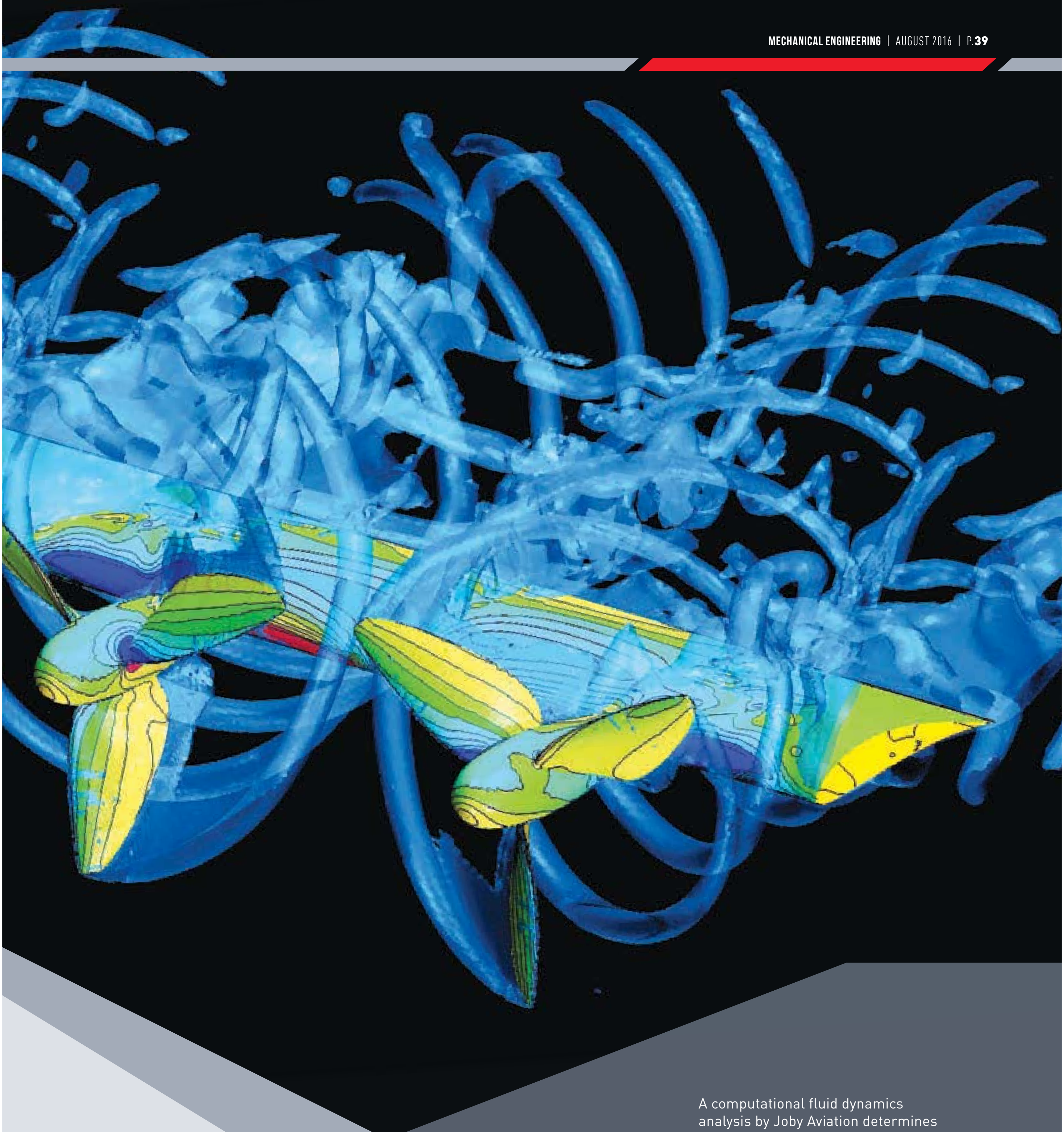
To take off, cruise, and land safely, fixed-wing airplanes need to generate enough lift to overcome the plane's weight and its aerodynamic resistance, or drag. They typically generate that lift from the aerodynamic force created when the plane's wings move through air.

But as NASA's engineers explained to Bain, their plan was for the wing-mounted propellers to blow air backward over the wings, generating extra lift. This effect, known as induced velocity, essentially tricks the plane into thinking it's going faster than it really is. It would help the plane cruise using less power, even with lightweight, thin wings that would never support a conventional aircraft.

But Bain couldn't get past the design. "It's just way too complicated," he said to himself while the NASA engineers described the project.

Despite his initial skepticism, Bain soon came around. He knew that he and other propeller designers were moving beyond the traditional two- or three-bladed aluminum alloy propellers powered by gas turbines or piston engines. Instead, they were building blades out of carbon fiber composites, and using them in innovative propeller designs with four, five, and even more blades. Those propellers, thanks to new electric motors, could be placed almost anywhere on an aircraft to optimize performance.

These innovations are helping create one of the most exciting eras in air-



A computational fluid dynamics analysis by Joby Aviation determines the optimal propeller and wing design for an electric-powered aircraft.

The Joby S2 integrates innovative propeller and wing design with new battery and electric motor technology for cleaner, more efficient air transportation.

craft design since the early 20th century.

After looking at the LEAPTech plans for a few minutes, Bain realized the project represented major trends that would continue to shape propeller design.

"You have all of this freedom to do things you never thought you could do," said Bain, who ended up working on LEAPTech, a phase of NASA's ongoing program to build and test a new electric propeller and wing assembly that could lead to quieter, safer, less polluting, faster, and more efficient aircraft. "Now you can go back to the drawing board and do something completely different."

In fact, he realized, by designing advanced propellers and using them in unprecedented ways, the work could help make improbable ideas about the future of flight a reality.

PROPELLERS TAKE SHAPE

Propeller design has changed in only small increments since 1903, when Orville and Wilbur Wright crafted propellers for their *Flyer* from laminated spruce boards. From the 1920s through the 1940s, changing military and transportation demands drove the development of more powerful airplane engines, which moved propellers faster, placing greater stress on them. Propeller makers responded with innovations in material design and manufacturing to handle the faster rotation speeds. For example, beginning in the late 1920s, propeller makers started to replace laminated wooden blades with solid steel and eventually lighter aluminum alloys, usually surrounding a wood core to dampen vibrations.

Design changes incrementally in mainstream aviation, and major design innovations are rare. If an aircraft has a strong safety record, as the industry sees it, there's no reason to change it until an absolutely rock-solid, proven change comes along to replace or augment a standard.

This is especially true for propellers. The way they work is incredibly complex, making it difficult to customize and quickly change the design without the aid of high-powered computers. One small change in the blade can jeopardize the performance and safety of the entire aircraft.

For that reason, propeller design has changed very little for more than half a century.

Today, though, NASA and aircraft manufacturers are demanding advances in propeller design as they look to create new types of planes, helicopters, and unmanned aerial vehicles (UAVs). These different kinds of aircraft require propellers optimized to carry out specific flight profiles: super quiet for take-offs and landings in residential backyards or busy commercial districts; light but incredibly tough for combat missions; low maintenance for long-term surveillance; highly efficient for commercial travel, and more.

In response, the mechanical and aerospace engineers who design propellers are innovating again. They're using new carbon fiber composites to make propeller blades that are stiffer, thinner, and lighter than those made from aluminum alloys. They're using inexpensive, powerful computers

NASA's LEAPTech designers mounted electric propellers on the front of thin wings. In ground tests (left), this created more than double the lift coefficient at lower speeds than traditional systems do. The artist's concept below shows NASA's planned X-57 Maxwell aircraft using a LEAPTech-type wing with 14 propellers powered by electric motors.

for quicker design iterations, which let them experiment with a greater variety of designs. And they're combining CAD software and advanced manufacturing tools like 3-D printers to combine composites to create prototypes, which they can tweak, scrap, and replace without worrying about the costs and time associated with manufacturing metal propellers.

Propeller design "used to be one size fits all," said Martin Albrecht, an engineer and general manager of MT-Propeller, a German manufacturer of high-performance propellers with U.S. headquarters in DeLand, Fla. "Now we can customize any propeller for any application."

NEW TWISTS ON PROPELLERS

A propeller blade is essentially a rotating wing. It transfers the power produced by an engine to force air to move through the diameter of the propeller or disc. When propeller blades are spinning vertically, as in a conventional fixed-wing commuter plane, that force generates the thrust that moves the plane through the air. When they're spinning horizontally in a helicopter or UAV, that force keeps the aircraft aloft.

To move air efficiently, propeller designers hone several key elements of a blade. These include the angle of attack, which is the angle at which the air hits the blade, and the pitch, which is the angle of the blade relative to the propeller hub. The pitch works like the grooves of a screw. The steeper the groove, the faster the screw bites into wood with each turn. Similarly, the greater the blade's angle, the more force it applies to the air to create airflow. Leonardo da Vinci described the designs for his flying machines as "aerial screws" for a reason.

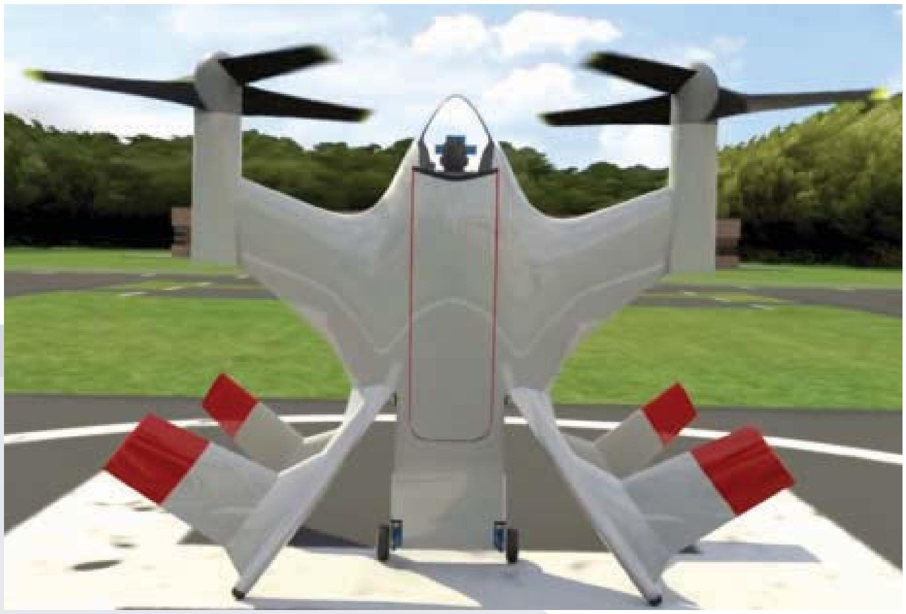
In propeller design, high power and low pitch is ideal for takeoff, while higher pitch and lower power is ideal for high-altitude cruising. To meet these conflicting demands, a variable pitch mechanism is used to automatically control the blades' pitch in flight.

Small or inexpensive aircraft forgo that for a fixed-pitch design—a compromise between takeoff, climb, and cruise performance requirements. Usually, the blade is twisted, with the pitch higher near the hub and lower near the tip. Increasing the camber or curvature of the blade creates greater thrust.

As a propeller spins faster and its tip speed approaches the speed of sound, its performance greatly diminishes due to drag and vibrations. Noise inside and outside of the cockpit also increases. Stronger, thinner, better balanced, and more aerodynamically efficient blades can help mitigate these problems.

Carbon fiber composites were introduced in the mid-1990s for many of the same reasons metal began replacing wood back in the 1920s. They are typically lighter than metal blades and allow designers to add more blades to the propeller without increasing its weight. Lighter blades generally contribute to a quieter, smoother flight. They also require less energy to spin, which decreases fuel consumption and reduces force on the propeller's hub.

"You just can't design a metal blade in



Concept aircraft like NASA's Puffin Electric VTOL (vertical takeoff and land) might never leave the ground, but they foster innovations that industry may eventually bring to market.

the same shape as composites," Bain said. "Composite blades are stronger, so you can make them thinner."

For LEAPTech and other leading-edge projects, engineers are also attaching propellers to new types of motors, and placing them in different arrays and positions on the aircraft that they didn't think were possible a few years ago. "Over the next 10 and 20 years there'll be tremendous growth in the types and designs of propellers," Bain said.

TECHNOLOGY DRIVES CHANGE

While new materials are important, engineers say faster, cheaper computers, along with the nearly limitless hardware and software resources in the cloud, have contributed the most to propeller design.

Bain, who performed aerodynamics and aeroacoustic calculations on composite rotor blades for NASA and DARPA as a research assistant at Georgia Tech, remembers when only large companies and well-funded institutions could afford the hundred thousand-dollar computer systems needed to perform the analysis and simulation for cutting-edge blade design. Today, Bain's small company solves complicated computational fluid dynamic problems and performs high-fidelity and blade element analysis by running resource-hungry programs on four Supermicro $5,000 blade servers with 128 processors.

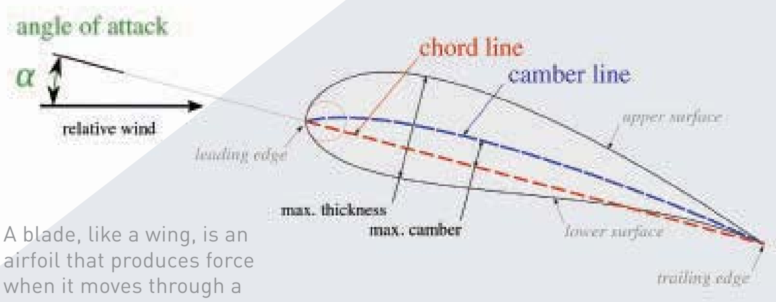
Affordable technology is also allowing many small companies to compete against the big boys and take risks that were once far too expensive and risky to attempt. "We can do things much more aggressively than in the past," Bain said. "Not only can we design the propellers, but we can also build them."

Engineers can thank 3-D printers for that.

When Joby Aviation, a Santa Cruz, Calif.-based company that's vying to be the Tesla Motors of the aviation industry, began designing a distributed electric propulsion system under a LEAPTech contract, it had to quickly produce prototype propellers for design validation and performance prediction tests. The team designed a propeller, shipped the computer model to a 3-D printing company, and had the prototype back at the office within two weeks. Based on that validated design, the team then built dozens of five-bladed, carbon-fiber propellers to use on LEAPTech.

For now, 3-D printing is suitable mainly for small prototype and test propellers that don't require the high-performance characteristics of a propeller used for actual flight. Larger propellers, especially those made from new carbon composites, require more sophisticated manufacturing methods.

For example, Joby is developing carbon-fiber propellers for use on its S4, a four-seat electric personal aircraft designed to take off and land vertically. The S4's propellers spin horizontally for upwards thrust in hover, takeoff, and landing modes, but they also tilt 90° to spin vertically, which provides forward thrust as the aircraft cruises. That tilting exerts a tremendous force on the propeller, which must be extremely stable and designed to minimize vibrations. What's more, the S4's propeller includes



A blade, like a wing, is an airfoil that produces force when it moves through a fluid.

five blades with a 10-foot diameter, which will experience even higher loads than shorter blades.

To counteract the enormous aerodynamic, centrifugal and gyroscopic loads on the propeller, Joby is leveraging high-performance composite materials like spread tow carbon fiber. These woven fabrics use thin and wide bundles of fiber or "tows" in a checkerboard pattern to create a more uniform laminate than common carbon-fiber fabric weaves. The new materials offer superior stiffness at a lighter weight, creating a higher performance propeller with greater stability.

Joby is also using an advanced carbon and metallic cocuring process to secure the blade directly to a titanium root that attaches the blade to the propeller hub. On a typical commuter plane, a propeller rotates at an average rate of 2,300 RPM, so fast that the blade tips approach the speed of sound. This creates centrifugal loads of about 10 to 20 tons per blade, enough to turn the slightest manufacturing flaw or in-service damage into a catastrophic failure. The co-curing process minimizes the number of pieces used to make a blade and reduces the chance of what's referred to as "departure," which is exactly what it sounds like.

GETTING AIRBORNE

By the spring of 2015, just two years after Bain's skeptical first take on LEAPTech, it was time to put the new design to a test. At NASA's Armstrong Flight Research Center in Edwards, Calif., engineers mounted the propeller-lined wing on a truck, drove it across the desert to gather and measured aerodynamic data such as lift and drag. The propulsion system produced enough lift to take off and land at the same speed as a conventional commuter plane, but with a smaller wing that's more optimally sized for cruise efficiency, the test showed. The lift coefficient (a measure of how much lift a wing can generate from moving air) was close to three times that of a Cirrus SR22, a single-engine aircraft with a much larger wing mass.

To reduce drag even further, the leading-edge propellers, which are used mainly for takeoff and landing, can be folded onto the propeller's nacelle when a plane cruises. Highly efficient propellers at the wingtips then take over to provide the thrust needed to pull the plane forward. Overall, LEAPTech indicated that a plane built to the new design would be 50 percent more efficient than the SR22 and required five times less energy for comparable performance.

The new phase of the LEAPTech project is called Sceptor, short for Scalable Convergent Electric Propulsion Technology and Operations Research. For this stage, NASA is replacing the wing from a Tecnam P2006T commuter plane with a LEAPTech-type wing to create a new single-passenger experimental plane called the X-57 Maxwell. NASA plans by 2019 to transition that design into a nine-passenger plane powered by a 500 kW electric power system driving 14 propellers and generating nearly 700 horsepower, compared with 100 horsepower produced by each of the Tecnam's engines.

The multiple propeller array is also much quieter than a conventional commuter plane. The slower-spinning blades generate a weaker pressure pulse per revolution than faster propellers, and a smaller pressure pulse generally means less noise. The small blades, driven by electric motors, sound more like the steady high-pitched hum of a fan than the ripping howl of a conventional propeller powered by a fuel-burning engine. Electric motors also allow engineers to adjust the propellers to direct noise above the plane, instead of toward the ground, making them quieter still.

"There's a lot of untapped potential for propeller design in conjunction with the vehicle," Clarke said. "As we explore more designs, we'll uncover more opportunities for increased propeller and vehicle performance." **ME**

JEFF O'HEIR is a contributing writer.

The Rise of the **DNA** Nanorobots

When designed properly, DNA folds into tiny devices that move like macroscopic machines.

BY **HAI-JUN SU** AND **CARLOS E. CASTRO**

The patient's fever has reached 104, he's drenched with sweat, and he can barely talk, let alone move. The doctor orders a blood test. Soon the diagnosis is clear: malaria. But throughout the region, malaria parasites have acquired resistance to the drugs meant to kill them. The doctors turn to the last-ditch solution. They send in the nanorobots.

Throughout the patient's body, the tiny robots home in on red blood cells, binding only to those that are infected, ignoring the healthy blood cells nearby. Then, one by one, they punch holes in the membranes of the infected cells, injecting a powerful drug that dispatch the parasites within. Later the body breaks down the nanorobots themselves, which are made entirely of DNA, into harmless byproducts, and the body safely excretes them.

Such a vision may seem fantastical, but it isn't so far-fetched. Working together, our research groups have pioneered methods for designing and building nanometer-scale mechanical devices whose motions can be precisely controlled. Our work opens a door to nanometer-scale robots (nanorobots) that can sense, respond to, and manipulate their local environment.

Our devices, which we developed with support from the U.S. National Science Foundation, also accomplish a task that macroscopic machines cannot. Their molecular components self-assemble into a working device with no help at all, much as the molecular complexes inside living cells do.

We have just begun to tap the possibilities of these self-assembling DNA devices, but in the future DNA nanorobots may be able to control chemical reactions, sense how fast fluid is flowing, measure forces exerted by a specific molecule, or change their shape to perform different tasks. They may even be able to manipulate various molecules and synthetic nanoparticles to fabricate even more complex nanoscale devices, much as industrial robots construct circuit boards or automobiles.

To build DNA nanorobots, we combined our expertise. One of us (Su) had previously conducted research on kinematic theories for macroscopic mechanisms and robots. The other (Castro) had delved into the field of bioengineering known as DNA origami, in which DNA–the same molecule that carries genetic information–is folded into useful structures.

Both of us arrived at Ohio State at roughly the same time, and early on we decided to collaborate. By then bioengineers had used the DNA origami technique to fold DNA into 2-D and 3-D structures such as a smiley face, a five-pointed star, a tetrahedron, and a nanometer-sized pore. But most of these devices were incapable of motion, and ones that moved did so in a simple or poorly controlled fashion. Our central goal in teaming up was to apply the principles of rigid-body kinematics to design DNA origami structures that could carry out familiar mechanical motions.

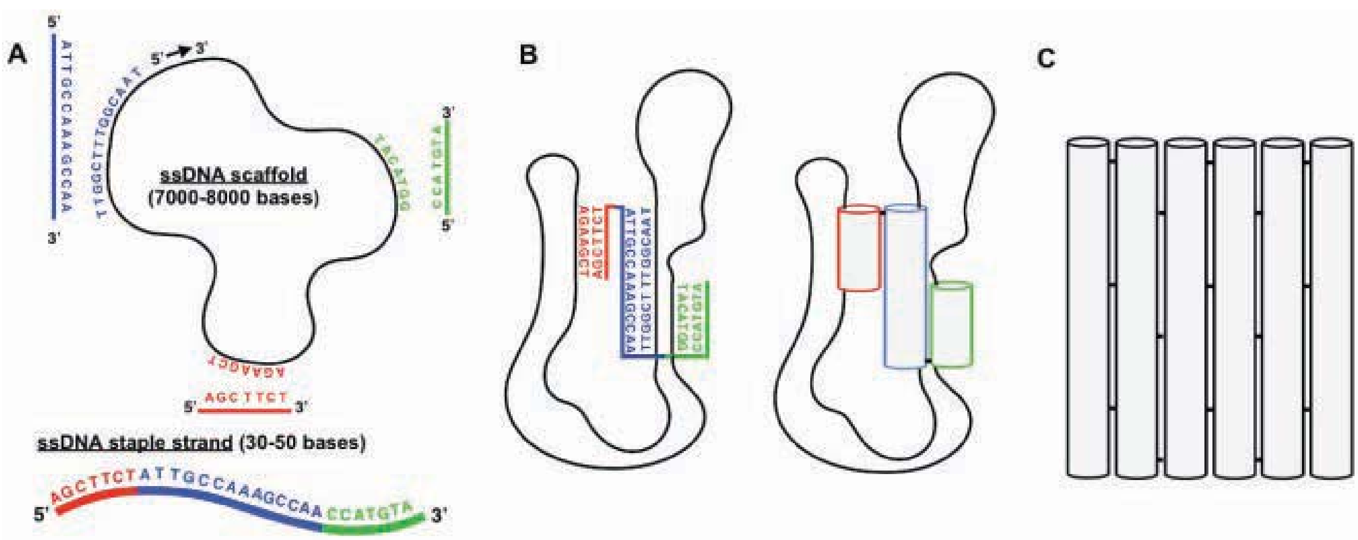
Folding DNA

Inside cells, DNA exists mostly as a twisting double-stranded ladder—the famous double helix discovered by American biologist James Watson and English physicist Francis Crick. But in the early 1980s, Nadrian (Ned) Seeman, a nanotechnologist and crystallographer at New York University, realized that DNA could also be induced to fold into more complex shapes. To do so, Seeman took advantage of two biochemical properties that allow DNA to encode genetic information.

First, each strand of DNA's double helix consists of a string of chemical building blocks called nucleotides. The four nucleotides that make up DNA contain components called bases that are often denoted as letters. (Specific sequences of these "letters" – adenine (A), thymidine (T), cytosine (C), and guanine (G) spell out genes, thereby encoding the myriad functions of living tissues.)

Second, when one strand of DNA encounters a second strand that matches it, the two zip together tightly to form a double helix. When the second strand does not match, according to rules

Building kinematic links with DNA origami



Short, custom-made DNA strands "staple" parts of a large DNA loop to each other (left and center), causing it to fold onto itself repeatedly to create a rigid link.

laid out by Watson and Crick, the two strands instead go their separate ways. The rules are simple: A's on one strand must pair with T's on the second strand, and C's must pair with G's. This allows scientists to design strands to either float freely or stick to each other and zip together.

Seeman had experimented with complex DNA structures such as a 4-arm junction that resembles the letter "X." In a moment of insight, he realized that giving DNA the correct sequence of nucleotides could program it to fold–on its own–into a specific nanoscale structure.

Seeman's insight and his follow-up work on the rational design and construction of DNA structures launched the field of DNA nanotechnology. Then, in 2006, the field underwent a quantum leap. That year Paul Rothemund of California Institute of Technology developed a new approach called scaffolded DNA origami. We have used this approach to build our mechanisms and machines.

Scaffolded DNA origami begins with a long loop of single-stranded DNA from a well-studied and harmless virus. This loop, called the scaffold, contains between 7200 and 8100 nucleotides.

As the DNA scaffold molecule wriggles and writhes in solution, it adopts many different configurations. Some of these place distant scaffold sections in close proximity. When designed with the correct nucleotide sequence, these scaffold sections bind to each other, causing the scaffold to fold in on itself to a degree.

To fashion more intricate folds, however, we also need short snippets of single-stranded DNA called staple strands. We design these strands, which are 30-50 nucleotides long, with a nucleotide sequence that enables part of the strand to bind to one scaffold section and part of the strand to bind to another. This holds the two sections close, much as a metal staple holds together opposite ends of a folded paper.

Simply adding a staple strand drives the DNA scaffold, which is a large loop of DNA, to fold into a particular shape, and it holds it there. Additional staples drive subsequent folding steps, ultimately fixing the DNA into the desired 2-D or 3-D structure. The strategic folding employed gives DNA origami its name.

Researchers have built a large and growing variety of complex DNA origami structures, including nanotubes; nanopores; and templates for proteins, nanoparticles, small molecules, and carbon nanotubes. But so far few of them can move in controlled ways.

DNA on the Move

To design the motion of a robotic arm or other macroscopic mechanism, engineers use the principles of kinematics. We used the same principles to design DNA origami mechanisms.

Kinematic theory assumes infinitely rigid links and infinitely flexible joints. In practical terms, this means that the links must be far stiffer than the joints. Double-stranded DNA exists as a double helix, a structure that's about 20 times stiffer than a strand of single-stranded DNA. For that reason, we use double-stranded DNA for the rigid links and single-stranded DNA for the flexible joints. We do this by inducing the scaffold to fold into double stranded structures in places and leaving it single stranded in others. We also make the links even more rigid—a thousand times stiffer than single-stranded DNA—by combining DNA double helices into bundles.

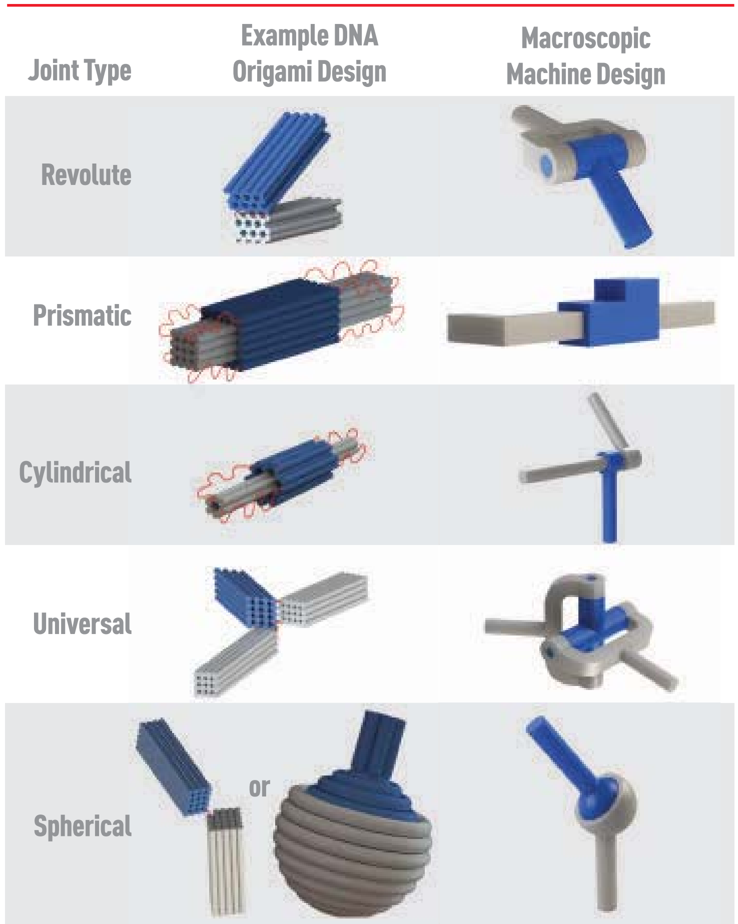
If we design the scaffold and the staples with the correct base sequence, we can control which parts of the final DNA origami structure will be double-stranded and which will be single-stranded. In this way, we determine the location of the links and the joints.

Recently we have developed ways to build DNA origami mechanisms with a variety of complex shapes. We do this by controlling the length, cross-sectional dimensions, and shape of a link, and sometimes by designing links with corners, branch junctions, or curves.

We can also design joints and control their flexibility and degrees of freedom. Typically we use a very short stretch (2-4 nucleotides) of single-stranded DNA to make the joint flexible, and we arrange these flexible regions to constrain their movement. For example, aligning flexible connections forms an axis of rotation, much as aligning two separate hinges on the edge of a door keep the door vertical as it opens. Another example is a slider joint where a pipe-like tube slides back and forth along a solid cylinder.

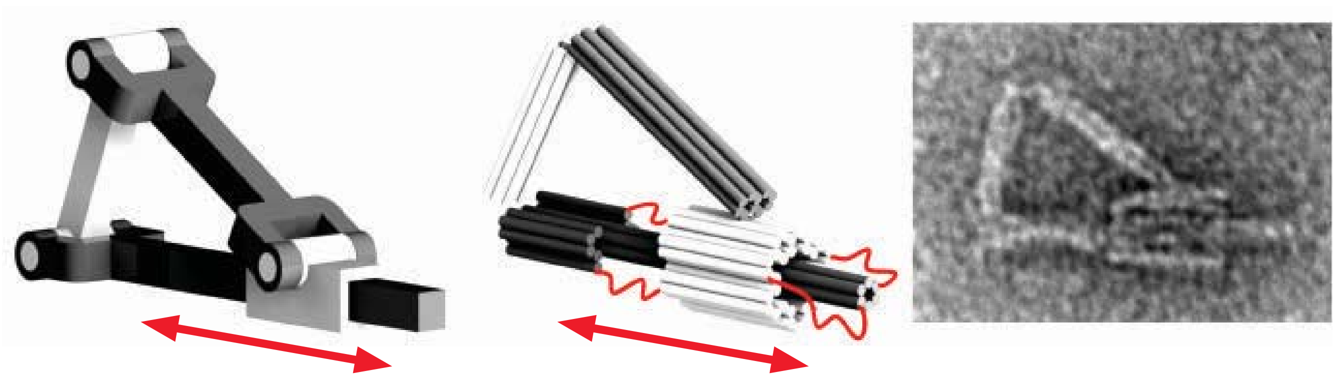
Over the past decade, bioengineers have trans-

From links to joints



Using a method called scaffolded DNA origami, the authors programmed DNA to fold into five common types of joints, from a revolute (hinge) joint to a spherical (ball-and-socket) joint. Each joint consists of rigid links (blue and gray) with a characteristic bundle of DNA double helices, connected by very short, flexible joints consisting of single-stranded DNA (red).

DNA Origami Mechanisms



A crank-slider mechanism (left) converts the energy of a rotating wheel into a linear back-and-forth motion, or vice versa. The authors built a crank-slider mechanism from DNA (center) by combining DNA origami links and joints.. They used electron microscopy (right) to visualize the tiny device and confirm that it actually moved.

formed the design of DNA scaffold origami from art to engineering. Now we can generate 2-D blueprints for DNA origami structures using an open-source computer-aided design program, caDNAno, then run those blueprints through simulation software called CANDO (Computer-Aided eNgineering for DNA Origami) to predict a 3-D folded structure.

We can also pull blueprints from catalogues of past DNA origami designs and modify them as needed, just as engineers do with CAD drawings. We can assemble components of a mechanism virtually as well. CANDO also lets us check for errors, and ensure we can fabricate the resulting molecule at high yields. All this reduces the need to perform experimental design iterations, which can be expensive and time-consuming.

To implement DNA origami mechanisms as nanorobots, we need to control their motion in real time. To this end, we recently adapted an actuation method that earlier DNA origami researchers have used to close DNA tweezers and perform other simple motions.

We built into our DNA origami mechanisms short sections of single-stranded DNA that each protrudes from the device like a sewn-on tag inside a coat. We distribute these tags throughout the structure. Then we add short snippets of single-stranded DNA we call "closing strands," each of which binds tightly to two of these tags. Binding two tags simultaneously pulls them together and drives the DNA origami device to move in a particular way. To reverse the motion, we add "opening strands"—single-stranded DNA snippets that lure the closing strands off the tags, releasing the device to reverse its motion.

To validate our design and fabrication strategy, we designed several joints with rotational and linear motion, including a hinge joint, a piston-like slider joint, and a universal joint like that in a car. We also combined these to form mechanisms with multiple degrees of freedom: a crank-slider mechanism that transforms rotational motion to linear motion or vice versa, and a Bennett four-bar linkage that folds up into a compact, closed bundle. Using transmission electron microscopy, we visualized the nanodevices in several conformations. As we'd hoped, their shapes matched the predictions of macroscopic kinematic theory closely, and actuation was reversible.

Toward a Working Nanorobot

Before we can combine our mechanisms into the type of nanorobot we envision, several technical challenges must be addressed. We've begun to tackle them, and we hope that other bioengineers and mechanical engineers will join us to advance the field.

New computational tools are needed to manage uncertainties in device self-assembly and in single-stranded DNA strand flexibility, both of which can alter a DNA device's kinematics. New computational and statistical tools are also needed to predict the final device's kinematics and dynamics.

Even fully folded DNA origami structures jostle and shift shape in solution, which makes it hard to control their motion. We've begun to address this challenge by building stiffer joints. To do so, we replaced single-stranded DNA, which is extremely flexible, with a few double-stranded DNA helices. These joints still deform by bending, much as a diving board bends and rebounds. We can then integrate these joints into what we call compliant DNA mechanisms. As a proof of concept, we designed a DNA origami compliant hinge joint and used it in a bistable four-bar nanomechanism that could execute the desired motion.

The design process for DNA origami mechanisms is still too cumbersome and error-prone, often requiring costly design iterations. New software that combines the capabilities of caDNAno and CANDO would streamline the process, creating a CAD-like program that would allow mechanical engineers untrained in biology to design DNA origami parts and mechanisms.

We also need better methods to validate a design. Transmission electron microscopy and atomic force microscopy help visualize these nanoscale structures, but they generate 2-D images that make it difficult to determine the object's true structure. We've developed a computational approach called projection kinematics that uses these 2-D images to calculate the device's 3-D structure. But a method that determines 3-D kinematic parameters directly would be better.

In addition, actuation currently takes several minutes, which is too slow for many practical purposes. Faster methods of triggering motion may be possible by changing ionic conditions, temperature, light, or a magnetic field. We also need new computational and statistical tools to better predict a DNA origami device's kinematics and dynamics, and a cheap, fast and high-throughput fabrication process.

As we and other researchers clear these hurdles, engineers will have a design tool and manufacturing method to build DNA origami mechanisms and more complex nanodevices and nanorobots. We envision a nanoscale equivalent of a walking robot that can travel from one position to another, a robotic manipulator or Stewart-Gough six-axis platform to precisely position molecules for specific tasks, and a mechanism similar to the crank-slider for injecting drugs into individual cells. But many other DNA devices are possible, and soon the field will be clear for practical applications of DNA origami mechanisms in sensing, nanomanufacturing, medicine–anywhere a controlled motion is needed at a nanometer scale.

At that point, in a clinic somewhere, a doctor may decide to send in the nanorobots. **ME**

HAI-JUN SU is an associate professor and **CARLOS E. CASTRO** an assistant professor in the Department of Mechanical and Aerospace Engineering at The Ohio State University.

More to explore

NUCLEIC ACID JUNCTIONS AND LATTICES
Nadrian C. Seeman in *Journal of Theoretical Biology*, Vol. 99, pages 237-247, 1982.

PROGRAMMABLE MOTION OF DNA ORIGAMI MECHANISMS
Alexander E. Marras, et al. in *Proceedings of the National Academy of Sciences USA*, Vol. 112, No. 3, pages 713-8, January 20, 2015.

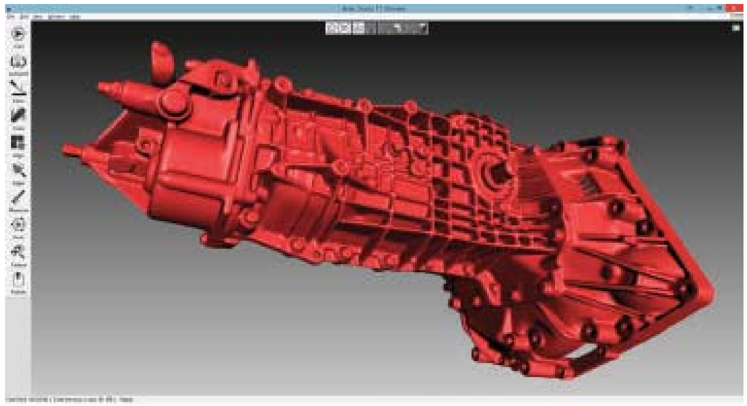
MECHANICAL DESIGN OF DNA NANOSTRUCTURES
Carlos E. Castro, et al. in *Nanoscale*, Vol. 7, pages 5913-21, published online Feb. 6, 2015.

DNA ORIGAMI COMPLIANT NANOSTRUCTURES WITH TUNABLE MECHANICAL PROPERTIES
Lifeng Zhou et al. in *ACS Nano*, Vol. 8, No. 1, pages 27-34, published online December 8, 2013.

DIRECT DESIGN OF AN ENERGY LANDSCAPE WITH BISTABLE DNA ORIGAMI MECHANISMS
Lifeng Zhou et al. in *Nano Letters*, Vol. 15, No. 1, pages 1815-1821, published online February 10, 2015.

SCAN TO MODEL

ARTEC 3D, PALO ALTO, CALIF.



Artec Studio 11 is the latest release of software designed for use with Artec's professional handheld 3-D scanners as well as a range of sensors. The application boasts a number of automated features, including an autopilot mode, to create professional-grade, 3-D models of any size. Artec Studio 11 enables the seamless integration with CAD programs such as Solidworks and 3D Systems's Geomagic Design X. The new platform also adds the CAD-required NVIDIA Quadro to its list of compatible video cards in order to support the seamless scan-to-CAD workflow. Also, Macintosh users can now directly capture 3-D data by using Artec's new ScanApp in combination with an Artec Eva scanner; the scans can then be exported to a Windows device for further processing in Studio 11.

DESIGN OPTIMIZATION

COLLIER RESEARCH CORP., NEWPORT NEWS, VA.

Collier Research has released HyperSizer Express, which delivers key capabilities of Collier's high-end HyperSizer tool. The professional version of HyperSizer was commercialized out of NASA, the company says, and has most recently been used to help design the heat shield of the space program's multipurpose crew vehicle. HyperSizer Express is a more user-friendly package aimed at the composite engineer. The Express interface guides the user step-by-step through the analysis process, with checkboxes on the status console to confirm current progress—from model import through material selection and FEA solver choice. The application is intended for such various uses as optimizing wind turbine blades or designing orthopedic prostheses.

PREPARE FOR PRINTING

MECSOFT, IRVINE, CALIF.

MecSoft Corp., the developer of CAD/CAM software applications, has announced the availability of Visual3DPRINT 2016, the newest version of a plug-in that runs inside the company's VisualCAD modeler. The plug-in offers automatic tools for preparing 3-D data that otherwise cannot be printed. The combination of VisualCAD's modeling and extensive file import functionality and Visual3DPRINT's data preparation tools enables the user to print models from almost any input source or 3-D format. Among the new features are support generation for holding up areas that have overhangs, determination of best orientation of geometry for printing, and the ability to select and manipulate selected portions of a mesh using a graphical manipulator. A free demo can be downloaded from the company.

CFD VISUALIZATION

TECPLOT, BELLEVUE, WASH.

Tecplot Chorus 2016 is a new version of the design-space simulation data analysis product that incorporates Tecplot 360 EX. The application integrates CFD post-processing, field and parametric data management, and powerful analytics into a single environment, so that an engineer using Tecplot Chorus can manage and analyze collections of CFD simulations and compare them in a single environment while evaluating overall system performance. For this new release, the company extended the color-by-filter violations for 2-D scatter to the table views to help even more with trade studies. That new capability makes it easy to identify where values lie in the range of all values and how close cases are to constraint boundaries. The new release also improves how the selected cases view works to help users rapidly identify cases of interest.

DESIGN FOR FIBER REINFORCEMENT

COMPOSIDE LTD., LONDON.

CompoSIDE v2.7.0 is a new version of an application intended for use in the product design process for improved development of fiber-reinforced plastics products. The new release features improvements to CAD file imports and group topology management functionalities within BoMGen, the automated bill of materials generation environment, for a seamless reporting experience regardless of the primary CAD system in place. The application now includes the coefficients of thermal expansion for layered materials and laminates, allowing a more accurate analysis of those components early in the design phase. Users can include the combined thermal mechanical loads and review the response analysis in LAMINASpace, using both tabular and graphical capabilities, and can specify either constant or variable thermal loading.

MODELING AND MESHING

MSC SOFTWARE CORP., NEWPORT BEACH, CALIF.

MSC Software Corp. recently released a new version of MSC Apex, which the company calls MSC Apex Eagle, to help improve assembly creation and to introduce new connections for abstracted parts. Those abstracted parts, dubbed computational parts, are designed to protect an engineer's intellectual property when sharing meshed geometry with colleagues. New connection types include rigid links, springs, and mesh dependent tie connections, which extend existing mesh-independent glue. In addition MSC Apex Eagle introduces the fifth release of MSC Apex Modeler, a CAE-specific direct modeling and meshing solution that accelerates CAD clean-up, simplification, and meshing workflow, and the third release of MSC Apex Structures, an add-on to MSC Apex Modeler which expands MSC Apex to a fully integrated and generative structural analysis solution. The company has also created a free edition that students can download and use on their personal laptops.

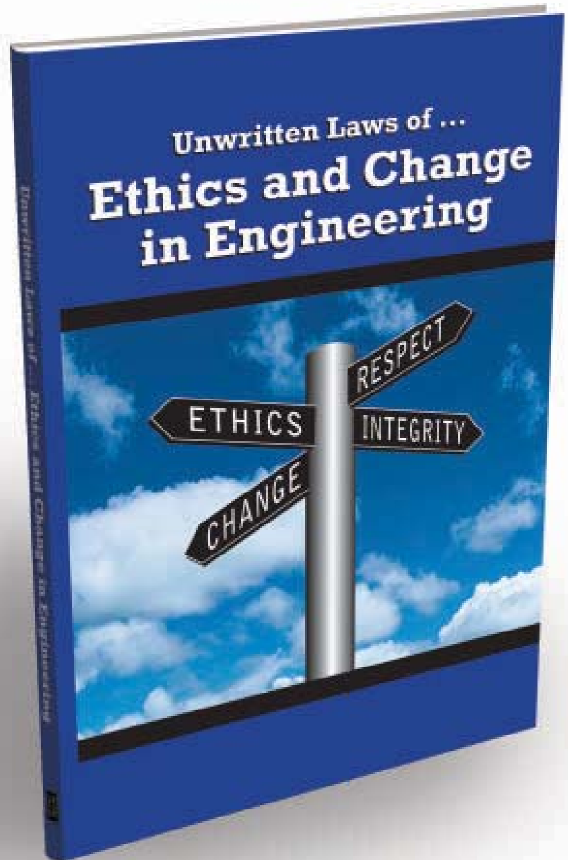
PROJECT DOCUMENTATION MANAGEMENT

BLUEBEAM, PASADENA, CALIF.

Bluebeam Revu 2016, the flagship product from Bluebeam Software, combines powerful PDF editing, markup, and collaboration capabilities with new features designed to enhance digital project documentation management and reporting. For instance, the application's batch markup summary enables users to report on and export data from multiple PDFs, simplifying the communication and manipulation of data important to large projects. Revu 2016 allows users to easily "tag" sheets by sheet number, sheet name, drawing date, and revision number to provide enhanced navigation and sorting of unlimited PDFs. The software is intended for use in the architectural, engineering, construction, and oil and gas industries.

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.



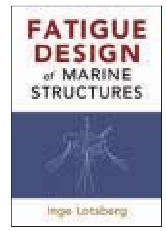
FEATURED

UNWRITTEN LAWS OF ETHICS AND CHANGE IN ENGINEERING

ASME Press Books, Two Park Avenue, New York, N.Y. 10016-5990. 2015.

Recent revelations about scandals at German and Japanese carmakers have put engineering ethics back in the spotlight. With luck, *Unwritten Laws of Ethics and Change in Engineering* can promote more ethical engineering. The book is based on two popular ASME online self-study courses: "Ethics for Engineers: Doing the Right Thing When No One is Looking" and "Changing Organizational Culture." It is intended for early career engineers and other practicing professionals to address non-technical topics that are often not taught in school. The book suggests that following ethics guidelines and codes may not be enough to avoid situations like the Volkswagen scandal. Engineers must know how to change company cultures to create an environment conducive to quality engineering.

120 PAGES. $29; ASME MEMBER $23. ISBN: 978-0-7918-6058-8.

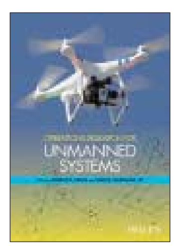


FATIGUE DESIGN OF MARINE STRUCTURES

Inge Lotsberg
Cambridge University Press, 1 Liberty Plaza, Floor 20, New York, N.Y. 10006. 2016.

Inge Lotsberg, a Norwegian engineer, distilled more than forty years of experience in design and standards-setting to write this guide to the basics of fatigue design of welded marine structures. He focuses especially on sailing ships, offshore structures for oil and gas production, and other welded structures subject to dynamic loading such as wind turbine structures. Such ships and structures are difficult and dangerous to inspect, making it imperative to understand the way fatigue works on large steel structures. "It has been interesting to observe a significant development of remote operated vehicles during the past 20 years," Lotsberg writes. "This has removed much of the need for using divers for underwater operations related to inspection and repair."

504 PAGES. $135. ISBN: 978-1-10712-133-1.



OPERATIONS RESEARCH FOR UNMANNED SYSTEMS

Jeffrey R. Cares and
John Q. Dickmann, Jr., editors
John Wiley & Sons, 111 River Street, Hoboken, N.J. 07030-5774. 2016.

Unmanned vehicles are becoming an inescapable part of the world, and they are changing everything from how we fight wars to how we design streetscapes. "As more systems are automated and dispersed throughout the battlespace or commercial work environment," write authors Cares and Dickmann, "there is an increasing need to understand how networks of collectives are effectively operated and controlled." Their book is an effort to meet that need, with a focus on the benefits of "unmanning" vehicles, improvement in operations that are achievable through UAVs, and the true costs of unmanned systems. Much of the focus is on military operations, but the lessons are more broadly applicable.

352 PAGES. $140. ISBN: 978-1-118-91894-4.

VERTICAL ELEVATOR STAGE

OPTIMAL ENGINEERING SYSTEMS, VAN NUYS, CALIF.

The AZ60-A motorized vertical elevator stage is a low-profile and compact device for applications requiring precise vertical positioning. Six crossed roller guides and a precision-ground lead ball screw provide vertical motion. Travel speeds are as high as 2.5 mm/s. The AZ60-A is constructed of black-anodized aluminum alloy and weighs just 1.14 kg (2.51 lb.). A 35 mm NEMA 14 1.8O 2-phase stepper motor has a double ended shaft with a knob for manual adjustments, though the knob may be replaced with a quadrature encoder for position verification. The non-cantilevered moving wedge elevator stage has a load capacity of 7 kg (15.43 lb.) without concern for loss of parallelism, and the base plate has easy-to-access holes for mounting.

LOW HEADROOM HOIST

ACE WORLD COMPANIES,
FORT WORTH, TEXAS.

Advantage electric chain hoists range from 1-ton to 5-ton capacities and come complete with a chain bag and four-button pendant. All units come standard with a mechanical load brake and undergo rigorous testing. Different speeds and lifts are available, as well as motorized trolleys and lug mount kits. All chain hoists come with a standard hook mount and require a three-phase power supply. Ace also offers standard monorail and top running wire rope hoists up to 10-ton capacity, typically utilized in construction applications. Higher capacity units are available upon request.

RFID ANTENNA

SIEMENS, NORCROSS, GA.

The Simatic RF680A is an adaptive antenna for Siemens's RF650R, RF680R, and RF685R UHF readers. The variable-polarization antenna (either linear or circular) simplifies the commissioning and planning of RFID applications, and an ability to automatically adjust the antenna adjustment increases both read and write reliability. The RF650R and RF680R readers have ports for four external antennas, allowing the implementation of four read points. In conjunction with the RF685R, two read points are possible. The antennas are compact (198 by 198 by 60 mm) and can operate at temperatures ranging from -13 to 167 °F. A transmission frequency range of 865 to 928 MHz allows the devices to be used internationally.

UNIVERSAL GRIPPER

SCHUNK, MORRISVILLE, N.C.

PGN-Plus-E is a digitally controlled mechatronic gripper with patented multi-tooth guidance. It is based on Schunk's PGN-Plus, though with improvements especially designed for mechatronic handling, with the multi-tooth guidance modified for higher moment capacity. The gripper also features a continuous lubrication pocket in the guide contour and the wedge-hook kinematics provides a high surface coverage in all stroke positions. The gripping force of the PGN-plus-E can be adjusted in four levels and the required control and power electronics are already fully integrated into the module. The mechatronic universal gripper is powered by a brushless DC servo motor, which the company says contributes to permanently high process stability and a long service life with minimal maintenance.

COVER ASSEMBLY

COINING, MONTVALE, N.J.

The new Coining ceramic cover assemblies are designed to offer advantages for the hermetic sealing of electronic packages. The assembly features one-piece, cover-frame construction, which may eliminate seal failures caused by misalignment of lid and frame. The company says its fully automated cover assembly manufacturing process and the use of an advanced and tightly controlled welding method for the cover-frame attachment process supports both low- and high-volume production requirements. Along with the ceramic cover assemblies, Coining says it also has improved the quality of and enhanced production capabilities for its metal cover assemblies.

PNEUMATIC PINCH VALVES

BIMBA, UNIVERSITY PARK, ILL.

Bimba's newly-designed Model 600 series pneumatic pinch valves are designed for a broad range of market segments and applications—especially those such as industrial, food and beverage, chemical, bioprocessing, and medical—where wash downs for sterility are essential. The 600 series is comprised of three models (603, 604 and 606) that support tubing outer diameters up to 0.375 inch, 60 psi media pressures, and hardness ratings up to Shore 70 material. The units all weigh less than a pound and are panel-mount ready, with easy tube loading and change-out head-designed slot features. The Model 600 series pneumatic pinch valves are available in single-acting, normally-open, closed, or double-acting formats.

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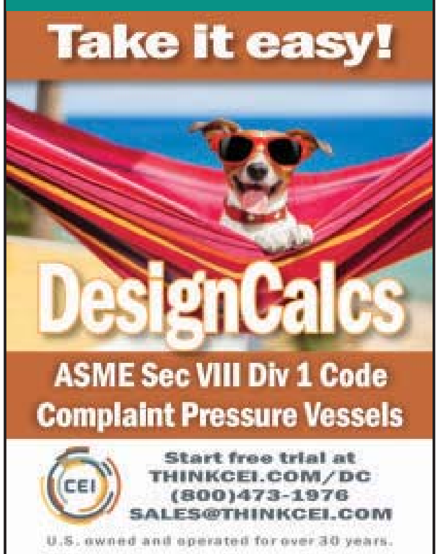

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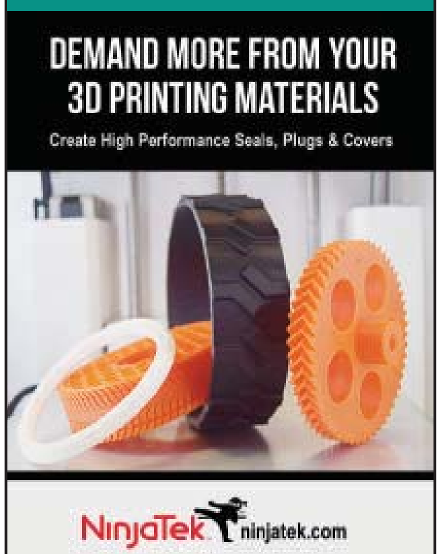


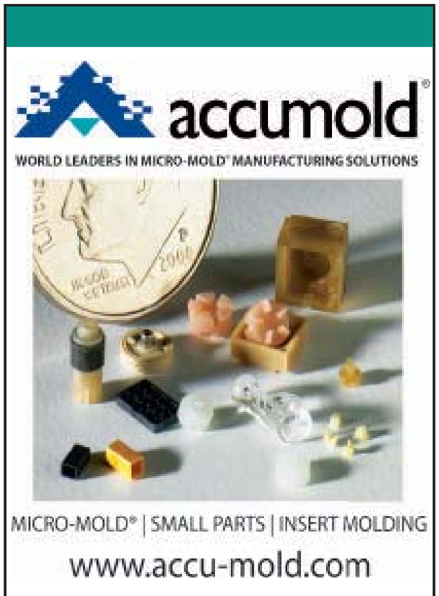
NINJATEK

OMEGA

REELL

TORMACH

SMALLEY



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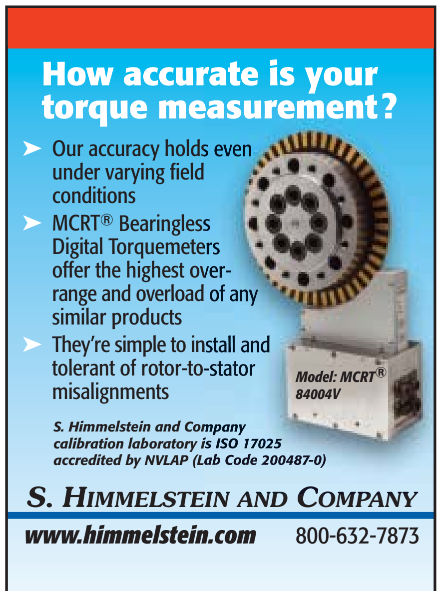

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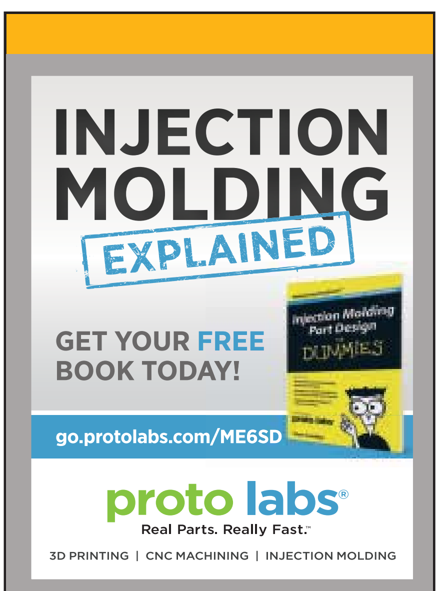

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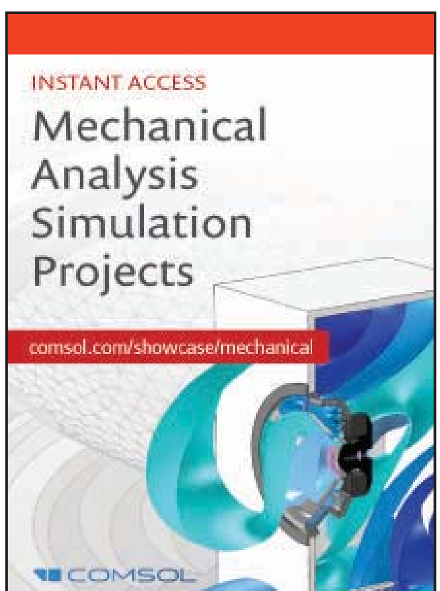

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If you are looking for information regarding an ASME code or standard committee, conformity assessment program, training program, staff contact, or schedule of meetings:

PLEASE VISIT OUR WEBSITE: WWW.ASME.ORG/CODES

COMMITTEE LISTING: For a listing of ASME Codes and Standards Development Committees and their charters, visit the Standards and Certification website at http://cstools.asme.org/charters.cfm.

CONFORMITY ASSESSMENT: For a listing and description of ASME Conformity Assessment programs (accreditation, product certification, and personnel certification), visit the Certifications webpage at go.asme.org/certification.

TRAINING & DEVELOPMENT: For a listing and description of ASME Training & Development educational opportunities, visit the ASME Education website at http://www.asme.org/kb/courses/asme-training-development.

STAFF CONTACTS: To obtain the ASME staff contact information for a Codes and Standards Development Committee or a Conformity Assessment program, visit the Codes and Standards website at http://cstools.asme.org/staff.

SCHEDULE OF MEETINGS: Meetings of Codes and Standards Development Committees are held periodically to consider the development of new standards and the maintenance of existing standards. To search for scheduled meetings of Codes and Standards Development Committees, by date or by keyword, visit the Standards and Certification website at http://calendar.asme.org/home. cfm?CategoryID=4.

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
Fasteners
Fitness-For-Service
Gauges/Gaging
Geometric Dimensioning & Tolerancing (GD&T)
High-Pressure Vessels Systems
Keys and Keyseats
Limits & Fits
Materials
Measurement of Fluid Flow in Closed Conduits
Metal Products Sizes
Metric System
Metrology & Calibration of Instruments
Nondestructive Evaluation/ Examination
Nuclear
Performance Test Codes
Personnel Certification
Piping & Pipelines
Plumbing Materials & Equipment
Post Construction of Pressure Equipment & Piping
Power Plant Reliability, Availability & Performance
Powered Platforms
Pressure Vessels
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Risk Analysis
Screw Threads
Steel Stacks
Surface Quality
Turbines
Valves, Fittings, Flanges, Gaskets
Verification & Validation
Water Efficiency for Plants
Welding, Brazing & Fusing

The ASME Standards & Certification section is published as submitted to Mechanical Engineering magazine by ASME's Standards & Certification Department.

POSITIONS OPEN

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY'S COLLEGE OF ENGINEERING in Prescott, Arizona, invites applications for a **TENURE-TRACK POSITION IN OUR MECHANICAL ENGINEERING DEPARTMENT**. The position is available in Spring 2017 at the Assistant/Associate Professor level. The department is particularly interested in interviewing candidates with experience in rocket propulsion systems. An earned doctorate in Mechanical or Aerospace Engineering and related experience is desired, but candidates with significant industry experience and a Master's Degree are strongly encouraged to apply. Application material should include a statement of professional goals and teaching philosophy, and contact information for three professional references. Materials may be submitted in electronic form through careers.erau.edu.

SIEMENS PLM SOFTWARE INC. has an opening in Coralville, IA for **PROJECT TEST ENGINEER** to provide quality assurance/quality control for motion simulation products. Mail resumes to Attn: Tiara Robinson/Req#155752, Siemens PLM, 2000 Eastman Drive, Milford, OH, 45150. EOE

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THE UNIVERSITY OF BRITISH COLUMBIA

MECHANICAL ENGINEERING FACULTY POSITION – Solid Mechanics

The University of British Columbia (Vancouver Campus) Department of Mechanical Engineering is accepting applications for a tenure-track position in solid mechanics. Those with research interests related to manufacturing and/or who use experimental methods are particularly encouraged to apply.

The appointment may be at the Assistant, Associate, or Full Professor rank, depending on the experience of the selected candidate. The starting date will be July 2017, or as soon as possible thereafter.

The mission of the Department of Mechanical Engineering is to serve society through innovation and excellence in teaching and research. Accordingly, candidates must demonstrate a commitment to students, teaching and learning. All members of the Department are expected to provide service within the Department, at the University, and to both the academic and broader community.

The ideal candidate will be eager to join an engaged academic community, and will complement our existing research strengths. With the support of their colleagues, they will develop an internationally-recognized, externally-funded research program.

The successful applicant will hold a Ph.D. degree or equivalent in Mechanical Engineering or a closely related field, and will be expected to register as a Professional Engineer in British Columbia. Industrial experience is an asset.

The University of British Columbia consistently ranks among the top twenty public universities in the world. Current strategic priorities include: student learning, research excellence, international engagement, sustainability, and creating an outstanding work environment. Please see www.mech.ubc.ca for more information on the Department, and www.apsc.ubc.ca/careers for more information on employment in the Faculty of Applied Science.

The University of British Columbia hires on the basis of merit and is committed to employment equity. All qualified persons are encouraged to apply. We especially welcome applications from members of visible minority groups, women, Aboriginal persons, persons with disabilities, persons of minority sexual orientations and gender identities, and others with the skills and knowledge to engage productively with diverse communities. Applicants are asked to complete the following equity survey: https://survey.ubc.ca/s/MECH-Manufacturing/. The survey information will not be used to determine eligibility for employment, but will be collated to provide data that can assist us in understanding the diversity of our applicant pool and identifying potential barriers to the employment of designated equity group members. Your participation in the survey is voluntary and anonymous. This survey takes only a minute to complete. You may self-identify in one or more of the designated equity groups. You may also decline to identify in any or all of the questions by choosing "not disclosed". Canadians and permanent residents of Canada will be given priority for the position. The position is subject to final budgetary approval.

Applicants should submit a curriculum vitae, a statement (not to exceed 4 pages) of technical and teaching interests and accomplishments, and names and contact information for four referees. Applications are accepted only through www.hr.ubc.ca/careers-postings/faculty.php, and must be submitted by September 15, 2016.

PennState College of Engineering | MECHANICAL AND NUCLEAR ENGINEERING

New Faculty Searches in Nuclear Engineering

The Department of Mechanical and Nuclear Engineering at The Pennsylvania State University is seeking outstanding applicants of all ranks to fill a tenure/tenure-track faculty position in nuclear engineering. The areas of interest span the full range of relevant topics in nuclear engineering.

The Mechanical and Nuclear Engineering Department is home to 55 faculty conducting in excess of $25M per year of funded research across a broad spectrum of traditional and emerging areas. The Department offers independent B.S., M.S., and Ph.D. degree programs in both mechanical engineering and nuclear engineering. The faculty in the Nuclear Engineering Program conduct state-of-the-art research on nuclear power with research connections to industry and government and benefit from international partnerships, sponsored by the new Global Nuclear Power Safety Center. The program benefits from the Breazeale Nuclear Reactor and the Radiation Science and Engineering Center for education and research. We have interests in nuclear power topics such as reactor physics and fuel management, thermal-hydraulics, nuclear materials, instrumentation and controls, nuclear safety, advanced reactors and nuclear fuel cycle analysis; and nuclear science such as radiation detection, nuclear security, non-proliferation. The nuclear engineering program has a vibrant resident graduate and undergraduate student population, and an established and successful online graduate program. Further information on the Department and on the Nuclear Engineering Program can be found at: http://www.mne.psu.edu/.

Applicants should have a doctorate in nuclear engineering or a related field, and have demonstrated outstanding scholarly research experience and teaching interests in nuclear engineering. Successful candidates will be expected to teach courses at both the undergraduate and graduate levels, to develop an internationally recognized, externally-funded research program, and to contribute to the operation and promotion of the department, college, university, and profession through service.

Applications will be considered until the positions are filled. Screening of applicants will begin on September 15, 2016. Applicants should submit a statement of professional interests, a curriculum vitae, and the names and addresses of three references who are Academics at the rank of Professor. Please submit these three items in one pdf file electronically to job 64301 at https://psu.jobs/job/64301.

CAMPUS SECURITY CRIME STATISTICS: For more about safety at Penn State, and to review the Annual Security Report which contains information about crime statistics and other safety and security matters, please go to http://www.police.psu.edu/clery/ , which will also provide you with detail on how to request a hard copy of the Annual Security Report.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national origin, disability or protected veteran status.

FACULTY POSITIONS IN MECHANICAL AND ENERGY ENGINEERING AT SOUTH UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA (SUSTC)

The Department of Mechanical and Energy Engineering at South University of Science and Technology of China (http://www.sustc.edu.cn/en) invites applications for **tenure-track or tenured faculty positions at all ranks,** commensurate with qualifications. The department is newly established with three broad directions of development, i.e., robotics and automation, innovative design and advanced manufacturing, and energy engineering. There are extraordinary opportunities to develop major research and education programs with collaborations with other academic/industrial organizations nationwide and worldwide.

Established in 2012, the South University of Science and Technology of China (SUSTC) is a public institution funded by the municipal of Shenzhen, a special economic zone city in southern China. Shenzhen is a major city located in Southern China, situated immediately north of Hong Kong Special Administrative Region. As one of China's major gateways to the world, Shenzhen is the country's fast-growing city in the past two decades. The city is the high-tech and manufacturing hub of southern China. As a State-level innovative city, Shenzhen has chosen independent innovation as the dominant strategy for its development.

The South University of Science and Technology is a pioneer in higher education reform in China. The mission of the University is to become a globally recognized institution which emphasizes academic excellence and promotes innovation, creativity and entrepreneurship.

Successful candidates are expected to establish vigorous research programs in the three broad directions and related interdisciplinary areas, mentor graduate students, participate in the national and international research community, and teach undergraduate and graduate courses. Candidates should possess doctoral degrees and demonstrate research accomplishment and/or potential. Senior candidates are expected to play the leadership role of research and education. Globally competitive salaries and start-up packages will be provided. Those interested are invited to apply through the job website at http://talent.sustc.edu.cn/en/enindex.aspx.

In addition, interested applicants should submit the following material electronically to rongym@sustc.edu.cn: 1) Curriculum Vitae (with a complete list of publications); 2) Statement of research interests; 3) Statement of teaching philosophy; 4) Selected reprints of three recent papers; and 5) Names and contact information of five references. Review of applications will begin immediately and continue until the positions are filled.

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

KEITH ROE CONFIRMED PRESIDENT

K. Keith Roe and Charla K. Wise

ASME's 135th president, **K. Keith Roe**, the former chairman, president, and chief executive officer of Burns and Roe Group, was inaugurated at a ceremony at the Society's annual meeting on June 7 in Louisville.

"I'm proud to continue my family's tradition of service and leadership at ASME," Roe said, noting that his father also served as ASME President and a major Society honor is named after his grandfather, Ralph Coats Roe. "It's a privilege and an honor to continue their legacy and that of preceding presidents and governors to fulfill ASME's mission and vision as an essential engineering and technology resource."

A Fellow of ASME, Roe was the founding chair of the ASME Industry Advisory Board and a member of the Board of Governors from 2008 to 2012, among other Society leadership positions. He has also been a staunch supporter of the ASME Foundation, having served as member of the Foundation's Board of Directors from 1991 to 2008 and board chair from 1994 to 2007.

During the President's Dinner, the ASME Nominating Committee announced the selection of **Charla K. Wise** as ASME president-nominee for 2017-2018. Wise, a resident of Colleyville, Texas, is a consultant and an adjunct professor of aerospace engineering at the University of Michigan. She has worked in a variety of capacities in the aerospace industry, including leading Lockheed Martin's F-22 Raptor Program Integrated Product Team through the development, critical design review, and first flight of the stealth tactical fighter aircraft.

The Nominating Committee also named three Board of Governors nominees: **Stuart W. Cameron**, a consultant to the energy engineering firm Doosan Babcock; **Bobby Grimes**, a technical advisor for the drill bits product line at Baker Hughes; and **Mary Lynn Realff**, an associate professor at the Georgia Institute of Technology. ME

START-UPS SHARE PRIZE AT ISHOWS IN INDIA, KENYA

Start-up companies and social innovators were named the winners of the 2016 ASME Innovation Showcases in India and Kenya. IShow India was held April 28 at the Le Meridien Hotel in Bengaluru (Bangalore), while IShow Kenya was a month later at the Golden Tulip in Nairobi.

Another IShow event in Washington, D.C., has also been held, though the winners of that event were not known at press time.

The three winners at each site were part of a group of hardware innovators who presented their prototypes and pitched their concepts.

In India, Adiuvo Diagnostics, a company that launched earlier this year, won with its Dermascope, a hand-held instrument that uses light to detect and monitor skin diseases non-invasively. A second medical start-up, Bempu Health, won for its entry, the Bempu Hypothermia Alert Device, a baby bracelet that detects neonatal hypothermia and sends audio and visual alerts to mothers.

The third winner, Chakr Innovation, was selected for its product, inC, a system that collects exhaust from diesel engines and converts the soot into ink and other products for the textile industry.

At IShow Kenya, the winners were the Banza Waterless Toilet, created by industrial designer **Patrick Kiruki**, which was conceived as an in-home toilet that separates liquid and solid waste using disposable, biodegradable bags; the Green Rock Drill, developed by mechanical engineer and former miner **Lawrence Ojok**, which captures the hazardous dust produced in the mining process; and **Taita Ngetich**'s Smart Mobile Farming system, which is intended to improve and automate drip irrigation by using sensors to monitor temperature, humidity, soil moisture, and other conditions.

The three winners at each site shared $50,000 in prize money. The businesses can use that money to further develop their products and bring them to market.

In addition to seed money for product development, the IShow winners also receive extensive design and engineering reviews of their products by a panel of industry experts.

To learn about the other IShow finalists, visit thisishardware.org/competition/ 2016/india and thisishardware.org/competition/2016/kenya. For more information on the IShow program, visit https://thisishardware.org. ME

KOTB RECEIVES NATIONAL BOARD'S SAFETY MEDAL

The National Board of Boiler and Pressure Vessel Inspectors recently honored **Madiha El Mehelmy Kotb**, presenting her with the Safety Medal at a ceremony held May 9 during the National Board's General Meeting in Kissimmee, Fla.

Kotb, a longtime National Board member representing the province of Québec, served as ASME's 132nd president in 2013-2014.

Kotb was nominated for the award, which is the highest honor bestowed by the National Board of Boiler and Pressure Vessel Inspectors, in recognition of her outstanding contributions in the field of boiler and pressure vessel safety. She was specifically cited for her enforcement of codes, laws, and regulations for the safe construction, installation, and repairs of boilers and pressure vessels, and for her service on many National Board and ASME committees. Kotb's nomination was approved unanimously by the Board of Trustees at its meeting in February.

Kotb is a resident of Montreal and a licensed engineer in Québec. She recently retired as head of the Pressure Vessels Technical Division for Régie du bâtiment du Québec, a board established by the provincial government to ensure the quality and safety of buildings and systems, including safety programs within the field of pressure vessels.

In addition to her term as ASME president, Kotb served the Society on the Board of Governors, as vice president of Conformity Assessment, and as chair of the ASME Presidential Task Force on Uniform (Financial) Reporting. ME

INDUSTRY AND TECHNOLOGISTS AT AM3D THIS MONTH

The ASME Additive Manufacturing + 3D Printing Conference & Expo (AM3D)—the only cross-industry event designed specifically for the engineering community—will take place from Aug. 21 to 24 at the Charlotte Convention Center in Charlotte, N.C.

AM3D will feature a variety of keynotes, technical presentations, panel sessions, and workshops focusing on the issues, challenges, and solutions associated with each step of the additive manufacturing lifecycle. The event will be held in conjunction with ASME's International Design Engineering Technical Conferences and Computers & Information in Engineering Conference.

One highlight of the AM3D program will be the keynote presentation by **Jose Coronado**, product manager for PTC, on Aug. 22. Coronado is currently a product manager for the Creo Manufacturing application, which now includes additive manufacturing capabilities.

Among the 40 other additive manufacturing professionals scheduled to speak during the conference are **Dan Berrigan**, additive manufacturing lead at the U.S. Air Force Research Lab; **Stacey DelVecchio**, additive manufacturing product manager at Caterpillar; **Brent Stucker**, co-founder and chief executive officer at 3DSIM; and **Jennifer Wolk**, additive manufacturing lead at the Naval Surface Warfare Center.

On Aug. 21, AM3D participants will have the opportunity to attend their choice of special workshops. These include the Design for AM Workshop, which will provide attendees with the fundamentals for successful AM optimized design, and the Topology Optimization Workshop, which will show attendees how AM can help them rethink their product design process.

To learn more about AM3D and to register, visit www.asme.org/events/am3d-conference. ME

FIRST 3-D PRINTER NAMED MECHANICAL ENGINEERING LANDMARK

ASME designated SLA-1, the first commercial rapid prototyping system introduced by 3D Systems, as a Historic Mechanical Engineering Landmark at a dedication ceremony in May at 3D Systems' headquarters in Rock Hill, S.C.

The SLA-1, which joins over 260 ASME landmarks around the world, was invented as a means to shorten the manual prototyping and design verification processes that preceded it. The system was developed in 1987 from the work of **Charles (Chuck) Hull**, the inventor of stereolithography and co-founder and chief technology officer of 3D Systems.

Hull invented stereolithography, or SLA, in 1983 as a rapid prototyping system that cures photopolymer resins layer by layer using UV lasers. Filed in 1984, the original SLA patent paved the way for new industries and new ways of thinking about design and manufacturing. By building parts one layer at a time, 3-D printing has also become a way to produce complex geometries with improvements to functional efficiency and reduced material costs.

"It's a great honor for 3D Systems, and for me personally, to receive recognition by ASME for our original technology," Hull said. "Although I expected 3-D printing to be embraced by manufacturers, I never could have anticipated how widespread 3-D printing is today, or the types of things that people are doing with it. For the past 30 years, we have had the distinct pleasure of watching our innovation spur more innovation, and we are excited to continue to shape the future."

A plaque commemorating the landmark status is now on display next to the SLA-1 in the company's lobby. ME

Thomas Chase (left) and Thomas Kuehn tinker with the mechanism of a Flute and Violin Solo Piano (Paul Lösche, Leipzig, Germany, 1925). In a traditional pianola (illustrated below), air drawn though holes in the paper roll opens a valve, which applies a vacuum to collapse a pneumatic striker bellows.

Photo: Paul Udstrand, Illustration: North West Player Piano Assoc.

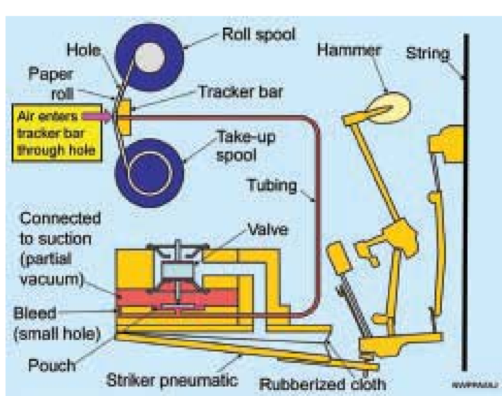
PLAYER PIANO PLAYERS

When Thomas Chase was seven, he put a coin into a player piano at a penny arcade. "This thing started playing music all on its own. I was instantly addicted," he said. His affinity for mechanical music stuck, evolving into an academic interest in mechanical design. But he never forgot his early fascination with century-old music boxes.

Chase is one of two mechanical engineering professors at the University of Minnesota, both ASME Fellows, who are helping preserve the history and artifacts of the mechanical music era, when machines played popular acoustic instruments. "They were developed when mechanics ruled—before vacuum tubes and electronic amplification," said Thomas Kuehn, the other professor.

Between 1910 and 1925, 85 percent of all new pianos included self-playing mechanisms. Player pianos, often called pianolas, were common in many households and coveted by most.

In a traditional pianola, a perforated paper roll travels over a tracker bar with 65 or more holes, each one connected to a pneumatic valve corresponding to a specific piano key. Inside the valves is a vacuum created when the player alternately presses dual foot treadles. When air enters through a perforation, a sensing diaphragm opens a valve, which enables the vacuum to collapse a small pneumatic bellows to actuate that key. Add a vacuum-powered motor and governor to drive the paper roll, and you have a complicated machine.



Fiercely competitive during their heyday, pianola manufacturers added features. Electrical power replaced foot pedals. Snare drums and tambourines kept rhythm. Organ pipes provided band and orchestra sounds, and advanced models with all these features—orchestrions—sounded like full bands or orchestras.

A major technological advance was the reproducing piano, which reproduced a piece exactly as an accomplished pianist had played it. A virtuoso pianist would play a special marking piano that inked a paper roll from which perforated rolls were later created. These perforated rolls had extra tracks to preserve the volume, tempo, and pedal action of the pianist.

One of Kuehn's favorite instruments, his rare Mason and Hamlin piano, came equipped with an Ampico B reproducing player, which, according to Kuehn, might be the best traditional vacuum system ever built.

Chase's collection includes a Link AX and a Seeburg E—both high-end orchestrions with special effects like a xylophone, snare drum, and tambourine. Housed in plush oak cabinets with elegant stained glass faces, these coin-operated beauties inhabited 1920s-era cafés and restaurants.

But by 1930 radios and phonographs with amplifiers and loudspeakers, which could reproduce the human voice, were replacing player pianos of all types.

Although many player pianos are spectacular examples of craftsmanship, technology, and novelty, in some ways an ordinary foot-pump model is the most fun, Chase said. "Pump harder and it gets louder, pump softer and it quiets down. You're part of it." ME

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