MECHANICAL
ENGINEERING

Technology that moves the world

THE MAGAZINE OF ASME

No. 06 137

POWER & ENERGY

GAS TURBINES ARE CHANGING THE WORLD — IN THE AIR AND ON LAND.

ASME.ORG

JUNE 2015

The biocompatible enzymatic roller pen writes biocatalytic materials directly on surfaces to detect pollution on leaves (top) or glucose levels through skin (below).

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

SENSOR SENSIBILITY

SENSORS FOR THE BODY AND THE BATTLEFIELD NEED NOT BE THE UGLY THINGS THEY'VE BEEN. Indeed, the days of the unattractive sensor have come to an end. Thanks to researchers at the University of California, San Diego, those hoping to measure their glucose level, gauge the concentration of heavy metals on a tire swing, or determine whether or not a suspicious personal electronic device is made of a plastic explosive can simply draw a sensor onto the surface in question, as intricate, elegant, and artistic as the user's hand will allow.

NEXT MONTH ON ASME.ORG

WILL CARS IN FUTURE BE 3-D PRINTED?

Hear from John Rogers, founder and CEO of Local Motors, an automotive company that manufactured the first fully functional 3-D printed car, on how microfactories could reshape American manufacturing.

PODCAST: THE FUTURE OF UNCONVENTIONAL SHALE PLAYS

Arthur Berman, president of Labyrinth Consulting, talks about the future of hydraulic fracturing based on the reported volume of oil and gas reserves and the emergence of renewable energy sources.

CRACKED GOLD FOR BROKEN BACKS

RESEARCHERS AT THE CENTRE FOR Neuroprosthetics at Switzerland's École Polytechnique Fédérale de Lausanne have created a new spinal implant that incorporates cracked gold. The implant has the potential to restore mobility to those with debilitating back injuries.

HUGS INFLUENCE EXOSKELETON DESIGN

WALKING INVENTIONS TO ASSIST PARAPLEGICS, stroke victims, and others with mobility issues aren't new, but Ekso Bionics is trying to help take development to the highest level.

VIDEO: INNOVATION FOR AFFORDABLE CARE

SHYAM RAJAN, CTO OF GE Healthcare India, discusses the innovations made by his company that have led to improved outcomes and improved lives for those in the developing world.

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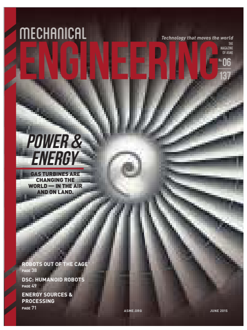

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SETTING THE STANDARD

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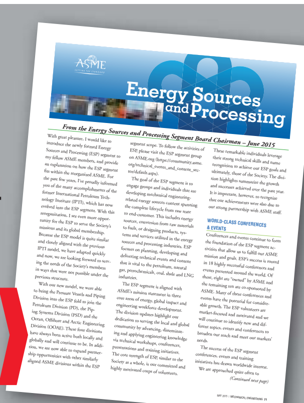

MECHANICAL
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Give me the place to stand, and I shall move the earth
—Archimedes

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John G. Falcioni
Editor-in-Chief

GETTING CLOSE TO WORKING CLOSER

The immediacy of the web and social networks has turned up the heat on the notoriously brutal big-city tabloid wars. Reporters are fighting harder than ever to be the first to break the news on which nightclub a certain NBA player was seen at last night, or be first to undress a local official who was caught with his hand in the town's kitty.

But technology magazines like *Mechanical Engineering* are usually spared such excitement. We certainly aim to be the first to spot technology trends, but not necessarily to break news. Our editors' unique lens helps them analyze the impact of technology in ways that other publications don't. Nonetheless, it's always great to run an article in the magazine and then see a similar story appear a few weeks later in a newspaper, a consumer magazine, or a business-to-business publication. This happens more frequently than you might suspect. Sometimes it's coincidence, but we prefer to believe that they read it here first.

Then there are instances like what happened with our "Work Buddies" article in this issue. When I was proofreading Alan Brown's article on collaborative robots that work side-by-side with humans, I spotted a similar article on the front page of the business section of that day's *The New York Times*. The newspaper called the article, "A Softer Side of Robotics." A day later, *The Wall Street Journal*'s front page had yet another similar article. This one headlined: "Factory Workers Warm Up to Their Mechanical Colleagues."

My first thought was: We got scooped! Now, as I sit here in front of my keyboard composing this month's column, I glance over to today's *Wall Street Journal* and I see yet another related front-page story. This one is about a robotics competition featuring automatons that don't just interact with humans; they also mix cocktails. ThinBot, for example, is four feet tall, has flashing lights, and makes 17 tasty drinks.

We've been covering developments in robotics technology and the convergence of robots and humans for decades. Other publications have too, and now the general media have realized the importance of covering robots in some depth. Great robotics stories abound and non-technologists should know what's around the corner—if not the technical details that engineers are interested in.

One of Brown's inspirations for the article came on a trip he and I took a few months ago to a Caterpillar plant in Clayton, N.C. CAT has been using state-of-the-art robotic systems for some time and it was clear to us that the interaction between robots and humans has gotten tighter and tighter.

Even though much of our visit to the CAT plant was "off-the-record" due to the proprietary nature of the systems they employ, Brown found other companies that would share anecdotes on how their robots mingle with employees. In researching the article, he convinced Universal Robots to bring one of its robots to our offices so we could, literally, shake hands and interact.

Having robots deftly work side-by-side in assembly and manufacturing plants is a major step forward in factory automation. It's also interesting to observe how comfortable human workers have become working alongside the robots.

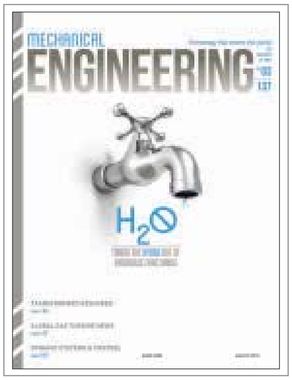
But because I don't work on a shop floor, I'd rather have one of the cocktail-mixing robots greet me when I get home, especially on days we get scooped by another magazine. Maker's Mark Manhattan up, ThinBot; stirred, not shaken—and don't forget the bitters. **ME**

FEEDBACK

Are robots taking jobs away from humans? Email me.

falcionij@asme.org

LETTERS & COMMENTS



MARCH 2015

Reader Rapoport takes on those who dispute climate change.

Two readers keep alive the ongoing dialogue over climate change. And another finds a justification for calling each snowflake unique.

DISREGARD AT YOUR PERIL

To the Editor: I for one think that it was a clever idea to rebrand global warming as climate change. It was clever, and interesting, but not in the deceitful way that Douglas L. Marriott suggests (Letters & Comments, March 2015).

We live in a world where a U.S. senator can use a snowball as a prop in an attempted debunking of empirical data that unequivocally shows that the Earth is warming. This clearly underscores that many individuals (including lawmakers) do not grasp the fundamental difference between climate and weather.

You can choose to disregard scientific consensus at your own peril as much as you like, but you shouldn't get to make decisions that might lead to the harm of others. We can already see the consequences of that kind of decision happening right now in the realm of vaccinations.

As an aside, Galileo is a terrible example. His heretical beliefs did not challenge a scientific consensus, but rather an ingrained religious dogma.

The Republic of San Marino in March issued a stamp saluting 3-D printing.

There are of course other examples of mavericks going against convention, but it was the convention of powerful industry. Consider Dr. Clair C. Patterson's fight against industry and industry-funded scientists to get leaded gasoline banned.

If you follow the money from the most vocal of climate change deniers, where does it go? To a well-informed scientific minority? Doubtful. The recent revelation that the poster boy for anthropogenic climate-change denial— Dr. Wei-Hock Soon—received approximately $1.2 million that he didn't disclose as a conflict of interest on his scientific publications is telling (http://tinyurl.com/lcc8ea9; http://tinyurl.com/pjofv6u).

How many people disagree that climate change is occurring (and yes, it is a well-documented warming)? You might find larger numbers of individuals disagreeing with the cause of climate change.

And why doesn't Mr. Marriott believe the data? He claims to have seen nothing that has convinced him one way or the other. That sounds suspiciously like an argument from ignorance—a logical fallacy for those who don't do their homework and something all too commonly displayed by armchair climatologists.

NASA has created an excellent page to address many of the common misconceptions about climate change and global warming (climate.nasa.gov). In fact, they address the use of "climate change" over "global warming" and provide definitions for both in their first frequently asked questions section.

Scott Rapoport, P.E., *San Diego*

TOOL FOR CLIMATOLOGISTS

To the Editor: This follows a series of letters on the subject of global warming published in the magazine during 2014 and more recently one from Douglas Marriott in March 2015.

In 2013 the Intergovernmental Panel on Climate Change issued a report that stated, "As one example [of the sensitivity to start dates], the rate of warming over the past 15 years ... which begins with a strong El Niño, is smaller than the rate calculated since 1951."

Note the use of "rate of warming." Published charts of global temperatures invariably use average anomalies—a positive anomaly indicating that the observed temperature was warmer than an earlier reference value. Large temperature variations are buried in the averages and there is no continuous analysis.

There is an alternative, engineering approach. An old friend, a retired U.K. Rolls-Royce aero engine engineer, John S. Jones, recognized that global climate is a process driven by the sun's energy and the prime product is temperature.

He applied his knowledge of Shewhart statistical control charts to analyze global temperatures.

Walter Shewhart was an engineer at Western Electric and Bell Research in the 1920s who developed the charts to assign probable cause of failures in manufactured products. A Shewhart chart is defined as "a graphical and analytical tool for monitoring process variation; the natural variation in a process can be quantified using a set of control limits."

John used National Oceanic and Atmospheric Administration temperature data from 98 land weather stations to develop Shewhart charts (x-axis from 1890-1990, and the y axis for temperature) in the conventional manner, with upper and lower control limit lines.

His graphs show continuous temperature plots generally tracking within the control limits and excursions (out of "control") which may indicate events—a change of energy (sunspot activity etc.) or a terrestrial influence (volcanic activity etc.).

There is no doubt that this engineering technique would be a revolutionary tool for climatologists to use.

Gordon N. Rogers, ASME Life Member, *Toronto*

ACKNOWLEDGING AGREEMENT

To the Editor: With regard to the letter appearing in the February 2015 issue from Craig R. Norris of Memphis, Tenn., regarding the June 2012 article, "Design in Nature," my letter addressing the same article appeared in the January 2013 issue.

I am gratified to note that Mr. Norris's reaction to the "constructal law" is identical to mine. So there are at least two engineers who refuse to accept this so-called law.

Marvin A. Moss, *North Hills, Calif.*

DEFINING 'UNIQUE'

To the Editor: The article titled "Every Snowflake Is Not Unique" in the January 2015 issue tries to address the question of uniqueness of snowflakes. However, it does not provide a direct answer to this question. Instead, the article focuses on the fact that all snowflakes "share one architecture, determined by the way heat flows."

Having the same architecture and following the same laws of nature, however, do not address the uniqueness question.

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.

Interestingly, while the article tries to disprove that snowflakes are unique, it presents a very good argument for their uniqueness.

It says, "To give credit to the view that every snowflake is unique, the actual configuration depends on many secondary effects, which are of random origin." This argument, contrary to what the article planned to show, is a reasonable justification for the uniqueness of the snowflakes.

Mehrdaad Ghorashi, P.E., *Gorham, Maine*

In the Galaxie gear drive, a cam raises and lowers spike-like gear teeth to make contact with the outer gear ring. The arrangement avoids backlash and significantly increases the contact surface to transmit movement.
Images: Wittenstein AG

RETHINKING THE GEAR

A NEW DESIGN HAS MOVING TEETH, NO GEAR WHEEL, AND INCREASED CONTACT.

After 2,400 years of development, it is hard to imagine anyone coming up with a totally new concept in gear drives. Yet Wittenstein AG unanimously won this year's €100,000 Hermes Award, one of the top prizes for engineering innovation, for doing just that.

"Everyone knows what a gear wheel looks like—and now, out of the blue, we're suddenly confronted with the idea of building a gear with moving teeth," said Johanna Wanka, Germany's Minister of Education and Research, when she presented the award to Wittenstein, a manufacturer based in Igersheim, Germany.

Moving teeth are just some of the new ideas in the drive gear, which is called Galaxie. To begin with, Galaxie dispenses with the gear wheel itself. Instead, it uses a series of independently moving but interlinked teeth supported by a needle roller bearing to transmit power from the shaft to the outer ring gear.

Those interlinked teeth do not move in a circular motion. Rather, they ride on top of a two- or three-lobed cam, which drives them in and out of the gear ring that surrounds them while moving them forward. The motion produced by the lobed cam traces a logarithmic spiral, which looks like part of a snail's shell or an arm of a spiral galaxy (which gives the drive its name).

The spiral motion solves a key limitation of conventional drives: the small number of gear wheel teeth in contact with the gear ring at any given time. The lobed cam drives most of the interlinked teeth into the ring gear at once.

The teeth are also unusually shaped: They

look like arrow tips. When driven into the V-shape gear ring slots, 6.5 times more surface engages the surface of the slots when compared to conventional helical-tooth planetary gears on the same size shaft.

The combination of more engaged teeth and greater contact surface delivers many benefits. According to Wittenstein, the Galaxie drive has 30-170 percent greater torque and 340-580 percent more torsional rigidity than conventional drives of a similar size. It can also handle hollow shafts that are up to 70 percent larger.

According to the drive's chief designer, Thomas Bayer, Galaxie produces virtually no backlash, even at the zero crossing, and achieves efficiencies as high as 91 percent.

Galaxie's moving teeth generate a protective hydrodynamic lubrication film, even at low speeds and at very high torque loads. After running 24/7 for two and one-half years, Galaxie showed hardly any wear or increase in backlash, Bayer said.

The company has been testing the drive with select customers for two years. According to Bayer, the drive's freedom from backlash and high stiffness and precision enables machine tool makers to run at higher cutting speeds and feed rates. This improves productivity and also part quality. He also thinks the gear would work well in robots.

The company announced the new drive at the Hannover Fair, which sponsors the Hermes Award. An animation of the gear drive is available on Wittenstein's website at www.wittenstein-galaxie.com/#funktionsprinzip. **ME**

ALAN S. BROWN

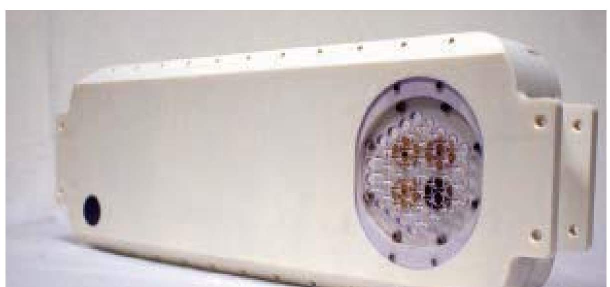
FIVE TEAMS VIE FOR OCEAN SENSOR X PRIZE

FIVE TEAMS OF RESEARCHERS are finalists for a $2 million award for pH sensors as part of the Wendy Schmidt Ocean Health X Prize. The competition is intended to produce instruments capable of cheaply and accurately monitoring acid levels in the oceans.

Rising levels of carbon dioxide are implicated with global warming, but the change in atmospheric composition has affected the chemistry of the ocean as well. Indeed, of every 100 kg of CO_2 emitted into the atmosphere, 30 to 40 kg wind up dissolving into the ocean or freshwater lakes and rivers. This dissolved CO_2 is, in turn, converted into carbonic acid, increasing the acidity level of the water and disrupting shellfish and corals.

Beginning in 2013, the X Prize Foundation opened a competition to international teams to develop marine pH sensing systems that would be tested both in laboratory conditions as well as the open ocean. Fourteen teams from five countries entered, and after two sets of trials, five finalists were selected:

• ANB Sensors (Cambridge, England), from the Schlumberger Gould Research Center;
• HpHS (Yokosuka, Japan), from the Kimoto Electric Co. Ltd. and Japan Agency for Marine-Earth Science and Technology;
• Sunburst Sensors (Missoula, Mont.), from Sunburst Sensors, LLC;
• Team Durafet (Plymouth, Minn.), from Sea-Bird Scientific, Monterey Bay Aquarium Research Institute, Scripps Institution of Oceanography at the University of California, San Diego, and Honeywell Aerospace Advanced Technology group; and
• Team XYLEM (Bergen, Norway, and Beverly, Mass.), from Aanderaa Data Instruments and YSI.



The ANB team's pHenom sensor can measure pH of low ionic strength solutions. Photo: ANB Sensors

The teams competed in open ocean trials in May. The week-long deep sea challenge will assess the sensors' ability to measure ocean pH values throughout the water column in a 110 square mile region about 100 miles off the northern shore of Oahu at depths of up to 3,000 meters.

The prize money will be given in two categories: accuracy and affordability, with $750,000 for first place and $250,000 for runner up in each. Winners will be announced in July. **ME**

A typical drill pad in the Marcellus Shale gas play of southwestern Pennsylvania.

HYDRAULIC FRACTURING'S GREENER TINT

THE UTILITY OF HYDRAULIC FRACTURING FOR oil and gas in the U.S. is proven in the results. U.S. crude oil production is at its highest level in three decades, according to the U.S. Energy Information Administration. Output has risen to 8.97 million barrels per day—largely because of fracking in the Bakken field in North Dakota and the northern Great Plains. Production from the Marcellus formation in Ohio, Pennsylvania, and West Virginia pushed U.S. output of natural gas to an all-time high in 2014, results solely attributed to fracking and horizontal drilling. But despite the technology's track record in tapping previously inaccessible sources of fossil fuel, the heavy industrial footprint put down by hydraulic fracturing rigs continues to draw opposition.

Developers now may have an answer to some of the environmental concerns. A well-driller, U.S. Well Services LLC, has developed cleaner technology to power fracking rigs. The company, based in Houston, claims its patented Clean Fleet technology has already decreased emissions by 99 percent, significantly reduced noise pollution, and saved operational costs of $40,000 per day at sites in West Virginia. The performance is based on equipment using field gas as a fuel, rather than commonly used diesel generators.

"If you run on natural gas, you save quite a bit on fuel costs," said Jared Oehring, director of technology for U.S. Well Services. "And there's a lot less noise." Compared to a typical diesel operation, noise is reduced about 70 to 75 percent, he said.

According to Oehring, the equipment is fully mobile, fully electric, and powered by natural gas. Diesel engines are replaced with electric motors and turbine-generators. Because natural gas is a much cleaner-burning fuel than diesel, nitrogen and carbon emissions are reduced by 99 percent. Fuel costs plummet using field gas, reducing operating costs by 80 percent, according to the company.

> **"COMPARED TO A TYPICAL DIESEL OPERATION, NOISE IS REDUCED ABOUT 70 TO 75 PERCENT."**
> — JARED OEHRING, DIRECTOR OF TECHNOLOGY, U.S. WELL SERVICES.

The first of the new equipment is being used in West Virginia by Antero Resources, whose executives say they have signed long-term contracts with U.S. Well Services for another unit. Oehring said the equipment has been in development for about two years. "We had to start from scratch," he said. "This is not a retrofit."

Typically, each fracking unit has been powered by a 2,250-hp diesel engine, Oehring said. "Basically,

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BROAD APPROVAL ON DEFENSE RESEARCH

A hearing by a unit of the House Armed Services Committee to review defense science and technology programs has resulted in agreement on several issues.

The hearing, held by the Emerging Threats and Capabilities Subcommittee, found members and witnesses generally agreeing on the importance of a vigorous defense S&T program to national security. There was universal recognition that the backbone of this program is a strong STEM workforce. Members also agreed about the importance of level funding for the Department of Defense's programs in basic research, applied research, and applied technology development.

Alan Shaffer, principal deputy, assistant secretary of defense for defense research and engineering, told the hearing: "Technological superiority depends upon a steady stream of investments in research and development. In constant fiscal year 2015 dollars, the research and development accounts have declined from $88 billion in fiscal year 2009 to $64 billion in fiscal year 2015. This level of decline, during a period where the United States is still at war, impacts the delivery of new capabilities most severely."

Shaffer was joined at the witness table by senior officials of the Army, Navy, Air Force, and Defense Advanced Research Projects Agency.

"We are all aware of the intense downward pressure the department is under these days and the ever-growing universe of threats that we are forced to deal with," said the subcommittee's chairman, Joe Wilson (R-SC), in his opening remarks. Wilson noted that the administration's overall request for funding in this area is above the caps in the Budget Control Act and would trigger sequestration.

Witnesses said sequestrration risked the loss of hard-to-replace defense scientists and engineers.

Shaffer said, "Over the past decade, the budget has declined precipitously. Coupled with the rise in capabilities developed by others, the nation is at increased national security risk."

The full hearing and witness testimonies may be viewed at tinyurl.com/DefenseR-D.


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GREEN FRACTURING

we've pulled the engine off and the transmission ... and put on an electric motor with variable frequency drive," he said. "We mounted the motor differently. There's a longer drive shaft. We've crammed a lot more into a smaller space."

The 14,500-psi fracking units are built to U.S. Well Services specifications by Stewart & Stevenson of Houston. The first unit has been operating since July 2014.

The equipment's reduced emissions are noteworthy, although Oehring points out that mobile off-highway power generators fall in between the cracks of federal and state regulatory rules.

"We're in a unique position," he says. "We're a generation ahead of where they're at." But he believes that Clean Fleet's operations will go a long way to satisfy critics.

Hydraulic fracturing continues to meet some stiff opposition, sometimes where it is unexpected. Voters in Denton, Tex., in the Barnett shale formation where the technology was first tested and proven, on Nov. 5 approved a ban on hydraulic fracturing. Proponents of the ban were largely residents upset that their homes were being encroached on by noisy, dirty industrial work, and its associated heavy truck traffic.

According to official results, the ban passed with more than 58 percent of the vote. More than 25,000 ballots were cast.

The Texas Oil & Gas Association has filed for an injunction, claiming a ban is inconsistent with state law. There are about 270 wells in Denton, some 30 miles north of Dallas, most of which produce natural gas.

What could give the Clean Fleet equipment a further boost is its quieter operations and the reduction of truck traffic because there are no diesel fuel deliveries.

"There are regulations on noise control and a traditional fleet cannot meet them without building sound walls. We can operate without disturbing neighbors," Oehring said.

He added that, in West Virginia, 25 diesel truck deliveries to the well site were eliminated for an average horizontal well completion, reducing traffic within communities while mitigating associated fire hazards.

In 2013, Halliburton and Apache Corp. announced a dual-fuel system to power hydraulic fracturing pumps on a blend of liquefied or compressed natural gas and diesel. They teamed with Caterpillar to adapt the manufacturer's Dynamic Gas Blending engine technology to the fracking system.

Caterpillar's Solar Turbines unit supplies Clean Fleet rigs with Taurus 60 mobile generator sets, each of which can produce upward of 5 MW.

JOHN KOSOWATZ, ASME.ORG

INTERLOCKING MATS TURN SHIPPING PALLETS INTO FLOORS

A demonstration of the E-Flör emergency flooring system. Image: E-Flör

You wouldn't know it if you haven't visited a refugee camp, but most of those white tents don't have floors.

That goes even for the prefabricated houses. As a result, millions of people live out the most challenging years of their lives subjected to parasitic infections, waterborne ailments, and hypothermia in colder climates.

Two students of architecture, Sam Brisendine and Scott Key, first noticed the problem when they were assigned a project through their program at Rice University in Houston, Texas, to design a temporary relief shelter. They shifted their attention to the floors and eventually devised an elegant design that ships well.

"We set out to design a raised flooring system that met all of the specific criteria unique to mass sheltering," Scott says. "That means cost-effective, highly mobile, incredibly flexible, and above all, warm, clean, and comfortable. We call this system the Emergency Floor."

Early on, Brisendine and Key stumbled across a parallel problem: supply chains. They needed a way to manufacture and deliver floors to the camps. The team crafted a first design that could be used as both a shipping pallet and a tent floor. Then they hit on a better idea.

Formal refugee camps are often located far from the cities of their host countries, and they require an enormous volume of shipments. Goods are packed on shipping pallets that arrive, but don't leave. The camps import far more than they export, generating piles of unused shipping pallets as waste.

Subsequent iterations of the shelter floor use the wood from pallets as support frames for the flooring. The flooring itself is a mat made entirely from post-consumer plastic. It's designed to fit over a pallet and link together with other mats to connect multiple pallets. The flooring units are modular: they can be attached in different variations to accommodate different housing structures and family sizes.

The floors are undergoing their first pilot in rural Sweden. The testing is in conjunction with a subsidiary of IKEA focused on relief shelters where the flooring has picked up a new IKEA-esque nickname, E-Flör. Brisendine and Key hope to begin two further pilots later this year in refugee camps in Lebanon and Iraq.

There were more than 46 million people of continued on page 20 »

HIGH ROADS NOT TAKEN

The best way to **not become replaceable**, is to put yourself into the position **of doing the replacing.**

Decisions you make in your thirties will haunt you the rest of your life. Clearly this is one of those statements that is true, but is not very helpful without clarification. I want to focus on career decisions.

Many of my friends and I, all in our fifties, are wondering how our careers ended up where they are. Actually my friends are wondering more than me, since I overanalyze things and have a relatively good idea how my career has come to pass.

Many of my friends are dismayed to find that they are now working for someone they have come to disrespect. In addition, some of them have either been threatened with or have barely avoided being laid off, despite the positive contributions that they have made to their organizations, in many cases over the last 20 to 30 years.

These individuals are in private industry, national labs, and universities. My wife's theory is that they make too much money and that is the reason their organizations are marginalizing them or laying them off.

I have a different view. Many of us passed on the opportunity to become managers when the opportunity arose in our thirties and forties. We wanted to do the fun work and not listen to the whining of subordinates and superiors, or attend meetings as managers.

When I was making $60,000 per year, I was asked to become a business manager in the company where I worked. I was told on a Friday that I would make $80,000 starting the next Monday if I said yes.

When I said no, the manager started to come over the top of his desk. When he was halfway across, I thought, "I don't think this old guy can take me!"

Right before he grabbed my lapels he came to his senses and dropped back into his seat. He apologized and then asked me "What the hell is wrong with you?" We did not have enough time in my remaining year and a half with the company to cover that topic in detail.

I have told my friends that I was going to write this article. It is not about bashing them, because I am their comrade in arms. It is actually a note of warning to younger people: You may make contributions to an organization as a working professional, but the organization certainly perceives the management staff to be more valuable.

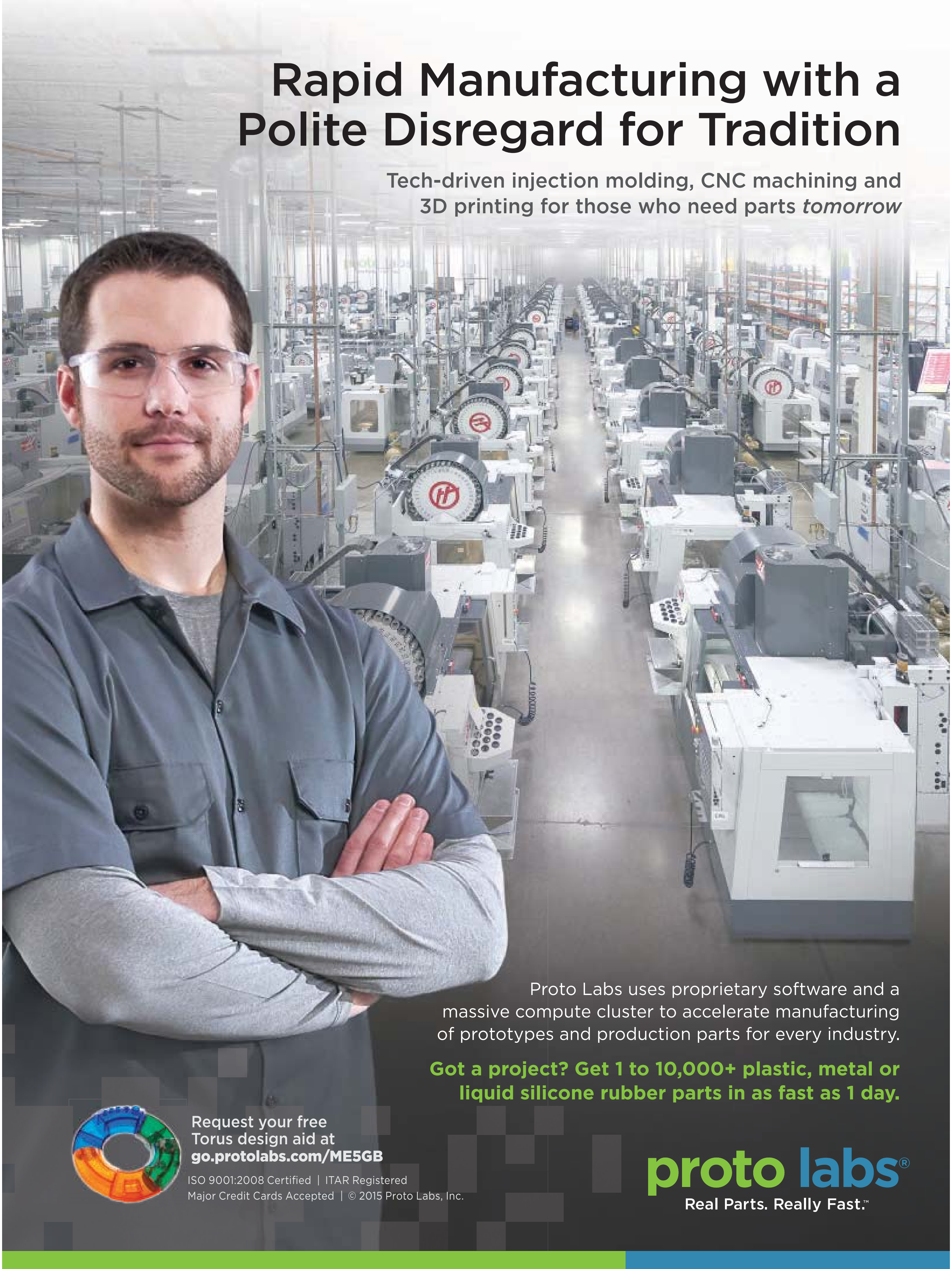
We are all replaceable, except the ones doing the replacing. Of course, they also get replaced when palace coups occur. I have to admit that some of the individuals who are marginalized in their fifties are a surprise to me. Their contributions and commitment to their organizations have been in my opinion quite extraordinary. However, their organizations clearly do not feel the same way.

When you are in your late twenties and thirties, look around you at the older individuals in an organization (especially those in their fifties). Employees in their sixties are living on borrowed time. A technical, non-management employee, even a Ph.D. in a national laboratory, has a window of value to the organization.

YOU MAY NOT WANT TO BE A MANAGER. I THINK IT IS FAIR TO SAY THAT THE HIGHER UP YOU ARE IN AN ORGANIZATION, THE MORE VALUABLE YOU ARE PERCEIVED TO BE.

You may not aspire or even want to be a manager. Becoming a manager, especially a mid-level manager, does not ensure that you will avoid being laid off. However, I think it is fair to say in general that the higher up you are in an organization the more valuable you are perceived to be. It can put you above organizational machinations, unless the palace coup—such as corporate merger or takeover—occurs. ME

RONALD A.L. RORRER is director of motorsports at the University of Colorado Denver.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Q&A BRIAN NOLAN

BRIAN NOLAN, CHIEF ENGINEER of aero-derivative gas turbine development for Siemens Canada, understands transformation. Since 2006, he has been involved in adapting Rolls-Royce's high-bypass Trent jet turbines into industrial turbines that can be used in remote locations and aboard ships and offshore oil platforms, as well as for distributed generation. The resulting engines run on a broad range of fuels while using dry low emissions—air cooling—to control pollution. (Siemens acquired the Rolls-Royce aero-derivative business in December 2014.)

ME: What was your goal in developing this new industrial dry low emission (DLE) turbine?

B.N: We're trying to demonstrate that DLE gas turbines can successfully operate on a wider range of gases. Gas turbines historically have operated on high-methane sources from natural gas fields. Over the years, we have seen fields with a wider and wider range of gases, including more associated gases.

Our customers want to run our gas turbines on those gases. In addition to methane, they include non-methane carbon molecules, such as ethane, propane, and butane. There are also inert gases, typically carbon dioxide or nitrogen.

ME: What were some of the challenges you faced?

B.N: When you consider the high pressure ratio and flexibility of large aircraft derivative turbines, there can be several challenges. The first is the battle for air used to cool the large combustion system surfaces versus the air we premix with natural gas to control emissions.
These high pressure ratios also generate combustion noise, and it can have a powerful effect on the hardware.

Lastly, these machines accelerate and decelerate rapidly. It's really important to thoroughly understand how transient hardware behavior and combustion unsteady effects combine to create complex emergent behaviors.

ME: You have been building DLE machines for more than a decade. What are some of the notable improvements in this new turbine?

B.N: Three particularly come to mind. On the manufacturing side, we introduced water jet drilled cooling effusion holes. They provide a smoother bore finish than laser drilled holes, which protects against crack initiation.

The second innovation involved using powerful 3-D computational fluid dynamics. This enabled us to look at unsteady combustion effects happening in tens of milliseconds, and really guided combustion design.

The last innovation involved design simplification. For example, we removed such features as the torch ignition system, and went with a simpler two-stage rather than three-stage fueling regime. We also built in passive acoustic dampening. Together, they really added a level of robustness and reliability to the overall combustion system.

ME: So where does your new turbine fit in? What are the applications?

B.N: With the growth of wind and other intermittent renewables, there is increasing demand for distributed power generation that can respond very rapidly to demand swings and stabilize the grid.

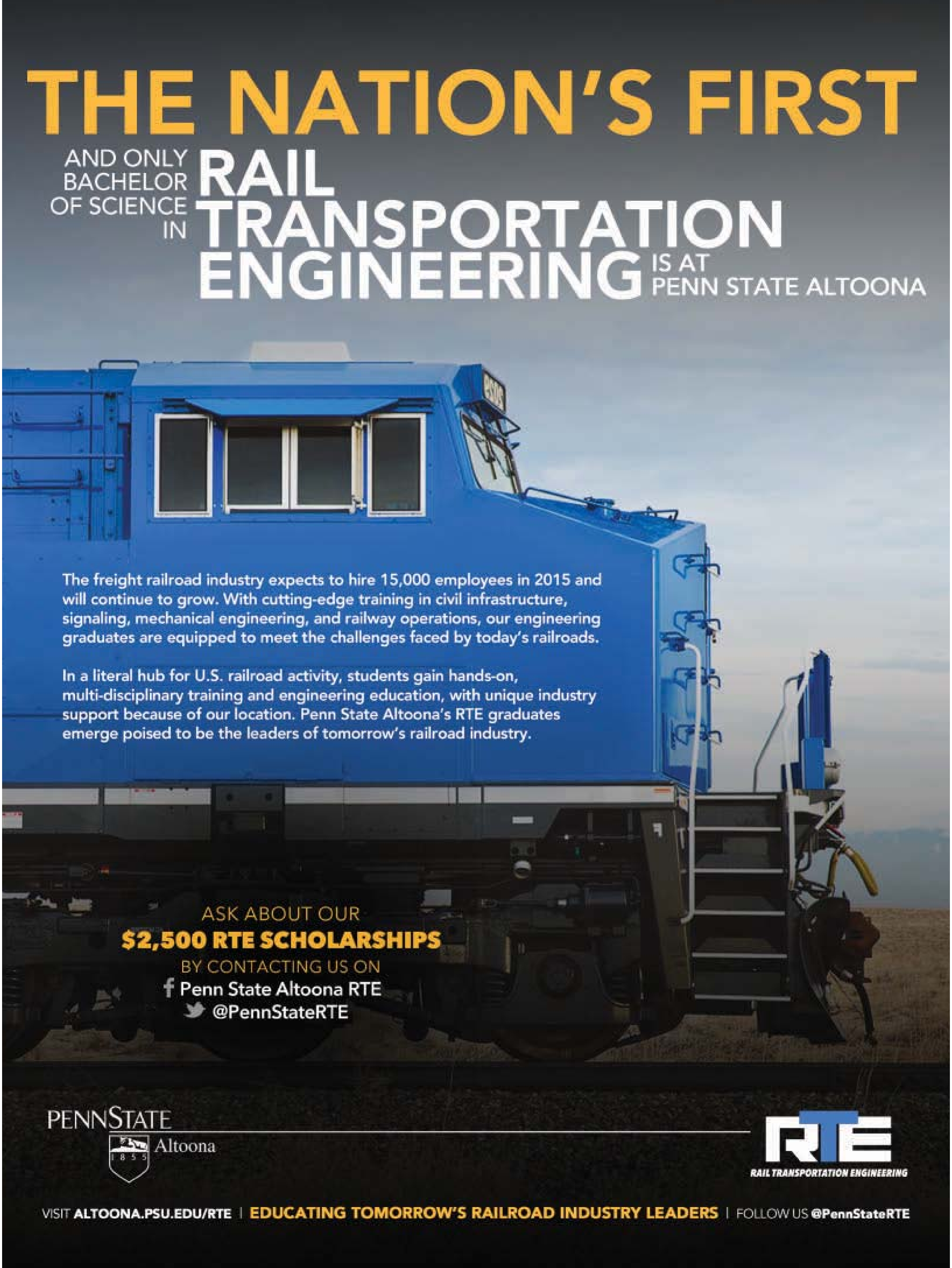
It gives oil and gas customers who need very high power density and a broad operating envelope access to low-emissions technology. Also, it can have a significant positive impact on the efficiency and life cycle economics of liquefied natural gas operations.

ME: What about future gas turbines?

B.N: There is still room to increase pressure ratios and efficiencies.
We also see benefits from our increased computational capability. We've already made great headway in our thermal understanding. I believe combustion noise will the next big area for design improvements. We also want to go to virtual test beds, so we can limit our engine testing.
We want to close the gap between DLE and non-DLE turbines, so that, at some point in the future, there will be no such thing as a non-DLE engine because DLE will perform just as well in terms of economics, efficiency, and reliability.

ME: So, how did you get involved in turbines?

B.N: What really drew me to gas turbines was that this field is on the cutting edge of a wide variety of technologies. As a development engineer, I got involved with everything from stress analysis and combustion engineering to controls and engine testing. It exposed me to lots of things that I had an interest in. **ME**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PALLETS INTO FLOORS

concern to the U.N. High Commissioner for Refugees in mid-2014, the latest date for which there are figures. That marks an increase of 3 million people from just six months earlier at the end of 2013. Although more than half of the world's refugees are in cities, not camps, four-fifths of them are in developing countries. That could leave tens of millions of people without floors.

Despite a broader shift toward non-tent methods of housing in formal refugee camps, the need has outpaced construction. And snowstorms pounding the eastern Mediterranean this winter have left tens of thousands of Syrian refugees at risk. Challenges aren't always volume-based: in the Gaza Strip for example, restrictions on cement import has made it difficult to rebuild housing foundations damaged in conflict.

Brisendine and Key founded the social enterprise Good Works Studio, Inc., to develop the Emergency Floor. Key views the for-profit element of production as a critical component of their mission.

"Social entrepreneurship means harnessing the principles of capitalism to very explicitly right societal wrongs," Key says. "It means taking a creative approach to what can be an incredibly destructive force in the world to create permanent, self-sustaining, positive change."

> "WE SET OUT TO DESIGN A RAISED FLOORING SYSTEM THAT MET ALL OF THE SPECIFIC CRITERIA UNIQUE TO MASS SHELTERING."
> — SCOTT KEY, CO-FOUNDER AND CEO, E-FLÖR

Brisendine and Key received seed funding and business guidance from Rice University's OwlSpark startup accelerator. For the two of them, the decision to take the project from the classroom to the field was an easy one.

According to Key, "When you see opportunities, doggedly pursue them and finish what you start. The world has far too many unfinished, well-intended projects."

JORDAN SCHERMERHORN, ENGINEERINGFORCHANGE.ORG

CHINA OKS BUILDING PILOT REACTORS

The Chinese government has approved the construction of pilot nuclear power units using a domestically developed reactor design called Hualong One, according to the state news agency, Xinhua.

According to an official statement issued after a State Council executive meeting in April, the approval is in line with global energy trends and will help optimize the country's energy structure and build a diversified clean energy system.

Hualong One reactor technology was jointly designed by China General Nuclear Power Group and China National Nuclear Corporation. It passed inspection by a national expert panel in August 2014. In November 2014, the National Energy Administration approved the use of the technology to build two reactors in Fujian Province.

A model of the Hualong One reactor, at the China High-tech Fair in Shenzhen.
Photo: Zheng Xiaohong/China News Service

The project will help nurture key equipment and core technologies, paving the way for China's nuclear power equipment to enter the global market, according to the statement.

Before the Hualong One was designed, China's nuclear power was using technology developed in the West and patented by U.S. and European companies, so export was forbidden. ME

SENSOR CAN GET A WHIFF OF ROTTEN MEAT

Careful shoppers always look to the sell-by dates on packages of perishable food. But those labels are estimates, not guarantees of freshness, and too often consumers don't discover that food has spoiled until they open the package at home.

Researchers at the Massachusetts Institute of Technology in Cambridge may have an improvement on expiration dates. They have developed an inexpensive, portable sensor derived from modified carbon nanotubes that can detect gases produced by rotting meat. Such sensors could signal spoilage without the need to even break the cellophane.

The research was funded by the National Science Foundation and the Army Research Office through MIT's Institute for Soldier Nanotechnologies.

Existing sensors can detect the odor of decaying meat, but they are large and cumbersome to operate. By contrast, the MIT sensor is small, cheap, and draws little power, enabling it to be incorporated into a special wireless platform that uses a regular smartphone.

The sensor is based on the principle that carbon nanotubes can be chemically modified so that their ability to carry an electric current changes in the presence of a particular gas. To build a device that can sense rotten meat, the researchers attached metal-containing compounds called metalloporphyrins to the nanotubes. Metalloporphyrins are a kind of molecule comprising a central metal atom bound to several nitrogen-containing rings; hemoglobin, for instance, is a metalloporphyrin with iron as the central atom.

The researchers used a metalloporphyrin with cobalt at its center. Such a molecule would be able to bind to compounds produced by rotting meat with such evocative names as cadaverine and putrescine, and increase its electrical resistance as a result. This change in resistance can be detected by a very simple device.

In a study published in April in the journal *Angewandte Chemie*, MIT researchers Timothy Swager, Sophie Liu, Alexander Petty, and Graham Sazama used the sensor to test the freshness of meats that had been refrigerated or left at room temperature. The sensor picked up the smell of decay from room-temperature meats, though refrigerated meat passed the sniff test even after four days. ME

VIRTUAL LABS

Elizabeth Baron (pictured below) has been the driver behind Ford's Immersive Lab, where designers and engineers at the company's labs around the world can collaborate to improve full-scale virtual prototypes of automobiles.
Photos: Ford Motor Co.

LONG-DISTANCE COMMUNICATION AT DARPA is keeping tabs on the integrity of key military microchips. Ford Motor Co., meanwhile, lets engineers and designers in far-flung sites try out cars that have yet to be built.

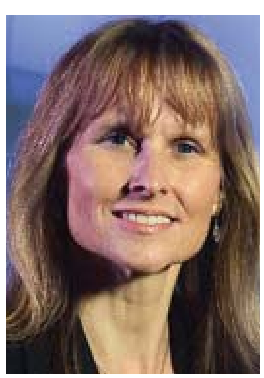
GLOBAL IMMERSION
THE LAB: Ford Immersive Vehicle Environment (FiVE) Lab, Ford Motor Co., Dearborn, Mich.; Elizabeth Baron, virtual reality and advanced visualization technical specialist.
OBJECTIVE: Detailed study of vehicle designs before physical prototypes are built.
DEVELOPMENT: Worldwide collaboration in real time to improve vehicle design.

Ford Motor Co. operates what may be called a doubly virtual lab. Engineers and designers view complete vehicles in immersive virtual reality long before any parts have been physically prototyped. What's more, connected labs at Ford sites around the world can collaborate on the same vehicle in real time.

In 2013, the latest year for which Ford provided information, designers and engineers checked more than 135,000 details on 193 virtual vehicle prototypes built in the Immersion Lab. Ford said that kind of detailed inspection would have been impossible a few years earlier.

Collaborative immersive labs are in various countries outside the U.S., including Australia, Germany, China, India, Brazil, and Mexico.

According to Elizabeth Baron, virtual reality and advanced visualization technical specialist, the connection of the labs is part of a program known as One Ford.



"We moved to the global One Ford plan so that international collaboration could lead to the development of globally appealing vehicles," Baron said. "With this technology, designers and engineers can enhance their ability to achieve that goal—while also improving vehicle quality."

Technologies include the Oculus Rift head-mounted 3-D display from Oculus VR of Menlo Park, Calif., and CAVE, developed by the Electronic Visualization Laboratory at the University of Illinois. CAVE, which stands for "Cave Automated Virtual Environment," simulates a three-dimensional space. The immersive representation lets engineers study issues of styling, craftsmanship, and ergonomics.

The lab uses an ultrahigh-definition display screen at the Immersion Lab in Dearborn, Mich., and at other Ford facilities around the world. According to Ford, the screen's resolution is four times the resolution of a high-definition television.

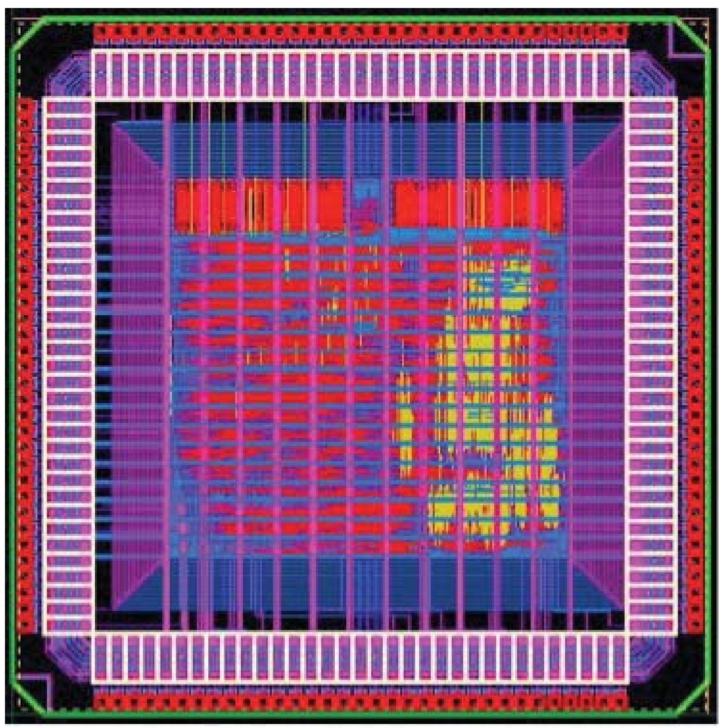
Engineers and designers can see inside and through a vehicle structure to study how various structural, mechanical, and electrical systems interact. They can sit inside a virtual automobile and touch, as well as see, the components.

Work in the Immersion Lab has informed a number of design decisions. It was after several iterations in virtual reality, for instance, that engineers determined that mounting sideview mirrors on the doors of the Ford Fusion enhanced visibility without compromising the design of the car.

Work in virtual reality also helped shape the 2015 Ford Edge. The lab's work helped improve the craftsmanship of the vehicle by eliminating visible fasteners and seams, and improving the fit and finish of the exterior sheetmetal. Full-length armrests in the Edge are another feature developed in the Immersive Lab.

According to Baron, who has been the driving force behind the company's use of virtual reality, "We now have Ford designers and engineers around the world working together virtually—inside and side-by-side—on the same product. By using this technology, designers and engineers can quickly transition from one car design proposal to another, and they can study and identify which is the best option." **ME**

Counterfeit chips delivered for military electronics can pose a threat to the U.S. services. So to ensure the performance of integrated circuits in military systems, DARPA, working in concert with the Naval Surface Warfare Center and Air Force Research Laboratory, has developed a virtual lab to manage the large volumes of data developed as microchips are analyzed and corrected.



Digital test articles studied in the Integrity and Reliability program include a 32-bit RISC processor (left) with 1.4 million transistors. *Photo: DARPA*

DARPA describes the lab as "an integrated CAD and file-sharing environment." A website for the virtual lab permits communication between government researchers and colleagues in academia and industry.

According to Kerry Bernstein, the DARPA program manager, integrated circuits are designed and manufactured at commercial sites in many countries. They are critical systems, so it is a matter of national security to assure that they have not been subject to tampering and will perform as specified.

"Improving chip intrusion detection and assessment speed across the investigative community will help prevent the installation of counterfeit chips in military systems and enhance overall confidence in the electronics supply chain," Bernstein said.

DARPA distributes samples to researchers, who subject the chips to workloads they will typically encounter in actual use.

In a recent investigation conducted by the Naval Surface Warfare Center Crane, Air Force Research Laboratory Wright Patterson, and University of Southern California's Information Sciences Institute, researchers devised a proprietary technique that can analyze and repair unreliable microchips. The team not only found the cause of erratic performance in a chip, but also corrected the fault.

They used a 1340 nm laser to alter the chip's circuitry. In the past, that repair required a focused ion beam and risked destroying the chip.

"Given how widespread microchips are, and their vulnerability to compromise, the numbers don't seem to be on our side," Bernstein said. "Through the virtual lab, however, we can help shift the balance in our favor. By extending testing resources to our service partners and working together more effectively, we can ensure the reliability of our most important electronic systems." **ME**

KEEPING CHIPS UP TO SPEC

THE LAB: Integrity and Reliability of Integrated Circuits program, Defense Advanced Research Projects Agency; Kerry Bernstein, program manager. With the Naval Surface Warfare Center and Air Force Research Laboratory.

OBJECTIVE: Assuring that microchips supplied for use in military electronics perform to specification.

DEVELOPMENT: A lab using the Internet and other resources to identify substandard or counterfeit chips.

SYMPOSIUM WEIGHS BIG DATA, ENERGY

The 2015 Engineering Public Policy Symposium in Washington, D.C., focused on big data, energy, and manufacturing issues. The event brought together more than 100 leaders from 44 national engineering societies representing more than two million engineers. ASME served as the chair and lead organizer of the event, which was made possible by a grant from the United Engineering Foundation.

The day-long symposium featured key speakers from the administration, Congress, and federal agencies who discussed strategies to encourage a resurgence in the U.S. manufacturing and energy sectors and the challenges and opportunities of big data.

Tom Kalil, deputy director for technology and innovation at the White House Office of Science and Technology Policy, as keynote speaker discussed the administration's emphasis on technology innovation, R&D, and the maker culture in the United States. Kalil asked engineers for support in promoting manufacturing events around the country—like the White House Maker Faire—to encourage the maker movement and a culture that celebrates engineering and science.

Several speakers addressed the use of big data and its impact on a range of industries. Suzanne Iacono, acting assistant director for the Computing and Information Science and Engineering Directorate at the National Science Foundation, highlighted some of the benefits of big data, including improved efficiency in transportation systems and a more stable electric grid. Irene Qualters, director of the Division of Advanced Cyberinfrastructure at the National Science Foundation, said that recent research and projects undertaken by NSF are expected to improve and develop a cyberinfrastructure that can advance the U.S. in the 21st century.

A panel representing various parts of the federal government examined the current state of U.S. manufacturing policy and looked at recommendations for future developments. J.J. Raynor, special assistant to the President for economic policy, talked about the continued progress of the National Network for Manufacturing Innovation. So far five institutes have been established and three are in development—one on flexible hybrid electronics, another on smart manufacturing, and the third on integrated photonics.

Michael Molnar, director of the Advanced Manufacturing National Program Office at the National Institute of Standards and Technology, asked all Symposium participants to encourage their organizations to participate in National Manufacturing Day on October 2.

Robert Ivester, deputy director in the Advanced Manufacturing Office for the Department of Energy, talked about the successes the DOE has had investing in many new technologies. DOE-backed research programs range from combined heat and power applications to advanced lithium batteries.

Erik Antonsson, a member of the National Academy of Engineering's Making Value in America Committee, offered a number of recommendations to move U.S. manufacturing forward in order to continue to be competitive in the global economy.

Speakers included Bruce Westerman, one of a handful of engineers in Congress, who said his experience in engineering and local politics inspired him to run for the U.S. House of Representatives. Westerman, an Arkansas Republican, said he is currently making efforts to apply his engineering perspectives to public policy.

Following the conclusion of the Symposium, outreach to congressional leaders continued. Participants met with their congressional representatives in the House and Senate to discuss engineering and science issues. Topics included budget priorities, federal funding to support manufacturing and R&D, and the Manufacturing Universities Act of 2015. ME

THIN MEMBRANE CAN KNOCK OUT AIRCRAFT CABIN NOISE

Like cramped seats, overpriced snacks, and excessive charges for checked bags, noise inside the passenger cabin is just one of the annoyances we've come to put up with on airplane flights. But few people realize just how much noise they have to endure. According to a 2006 study published by the Canadian Acoustical Association, cabin noise levels are a continuous 80 to 85 dB during flight. That's louder than standing next to a busy freeway—all the way from JFK to Heathrow.

Researchers at North Carolina State University in Raleigh and the Massachusetts Institute of Technology in Cambridge believe they have a way to cut that noise considerably. It's a very thin membrane that can be stretched across the floor and ceiling of the airplane cabin.

To keep airplanes lightweight, they are constructed with panels made from honeycomb-like composites. While strong, these stiff panels let low-frequency sound from the engine pass through into the passenger compartment. Sound-blocking insulation might help, but it's generally left out to save on weight.

To find an alternative noise-control material, mechanical engineers at N.C. State and MIT turned to adding a membrane of latex rubber just one-hundredth of an inch thick. When sandwiched between two rigid panels of honeycombed composites, the membrane could flex within the open cells, absorbing sound that might otherwise transmit through.

In spite of adding only about 6 percent to the weight of the panels, experimental results showed that a single membrane was able to cut sound by a factor of 100 or more. That's enough to make it easier to hear when a steward asks you for your drink preference.

The research was published in April in the journal, *Applied Physics Letters*. Yun Jing, assistant professor of mechanical engineering at N.C. State, was the senior author. **ME**

MANAGEMENT'S EXPANDING RESPONSIBILITIES

LOOKING BACK

Western culture was undergoing major social changes when this article was published in June 1965.

DAVID PACKARD, CHAIRMAN OF THE BOARD, HEWLETT-PACKARD CO., PALO ALTO, CALIF.

A highly successful entrepreneur 50 years ago looked at the changing social role of business managers.

As management has developed, particularly in the past few decades, it has become clear that the profession has responsibilities beyond improving the operating efficiency of the enterprises being managed.

Since the early years of scientific management, the major emphasis has been on the economic efficiency of the unit involved. Considerable attention has been given to human relations and much has been learned about this subject, but this has been done generally in an attempt to increase efficiency. The underlying philosophy has been that, if the manager is able to produce goods and services for which the market has called and produce them at a profit, his responsibility to society has been discharged well.

No one will deny that profit-making is, indeed, the most important responsibility of a manager, for if he fails in this, he is hardly in a position to do anything else. In the past few decades, the management profession has begun to realize that it does have responsibilities beyond the achievement of economic efficiency. Fortunately, many management people have finally recognized that they do owe something to their employees beyond an hourly wage for work performed, and that they and their business firms are somehow involved in the environment created around their affairs by the society at large.

The most evident understanding of management's broader responsibility has come about in employee relations. The change in attitude was motivated in part by unions and government, but there is ample evidence that the management profession has become self-enlightened in the matter.

Employees are now well recognized as human beings, not just as a commodity to be bought on the open market. Good working conditions, safety, sickness benefits, provisions for retirement income, and many other considerations for employees are now counted high on the list.

Managers have, in recent years, taken an active interest in many affairs outside the confines of their business enterprises. Interest and activity in the local community have been increasing at a healthy rate. For a long time there have been isolated cases of communities which have been made more attractive because of the interest and involvement of the local business management. Such interest has become commonplace in recent years, and now nearly every community in America is better in some way because professional management has considered the local environment to be important.

This interest has extended far beyond financial support for community projects. It has included active participation by business people in local governmental bodies, school boards, and other such groups. These participants are a benefit to the community because of their professional skills, and in such participation they have further extended their influence. **ME**

ADVANCING RIGHTS

The year in which David Packard's article appeared saw two watershed events in the advancement of human rights in the United States. In March, police attacked a group of peaceful demonstrators who were crossing the Pettus Bridge in Selma, Ala. The event spurred action that culminated in the federal Voting Rights Act, which was signed by President Lyndon Johnson in August.

Police halted the Selma to Montgomery march at the Edmund Pettus bridge in Selma, Ala.

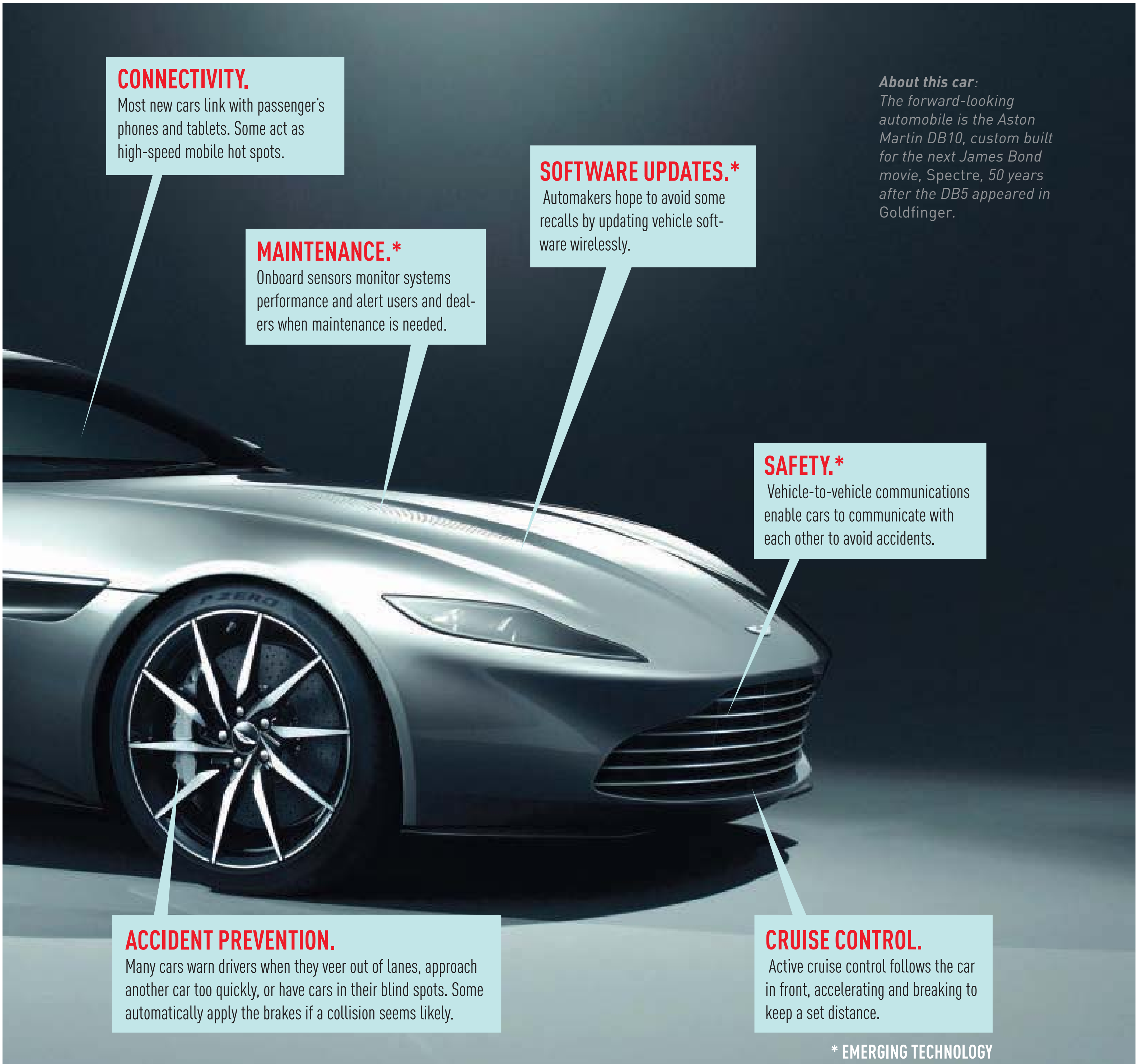
THE CONNECTED CAR

YOU'RE NOT SUPPOSED TO TEXT OR TALK ON THE CELL PHONE AS YOU DRIVE, BUT CARS ARE BECOMING COMPUTERIZED HUBS OF COMMUNICATION ON THE ROAD.

From ejector seats to remote-controlled driving, James Bond's car set the bar for exotic automotive technology 50 years ago. When it comes to extreme gadgetry, today's cars might give his famed Aston Martin a run for its money.

Every day, millions of people turn at least some aspects of their driving over to their automobiles. Sometimes, vehicles alert drivers when they veer from their lane or have a car in their blind spots. Other times, they autonomously maintain their distance in stop-and-go traffic or brake to avoid a collision.

Welcome to the new world of connected cars. By linking vehicles to sensors, mobile devices, the Internet, and one another, automakers are changing our expectations of safety, convenience, maintenance, and entertainment. This promises to upend how engineers design automobiles. Once, driving performance was all that mattered. Yet in a 2014 Accenture survey,



***About this car**: The forward-looking automobile is the Aston Martin DB10, custom built for the next James Bond movie,* Spectre, *50 years after the DB5 appeared in* Goldfinger.

drivers said they were twice as likely to choose a car based on technology as on performance. A full 90 percent were interested in autonomous driving options, especially those involving safety.

We are nearing a time when cars communicate with one another as they navigate highways to prevent accidents and reduce or even eliminate traffic jams.

These technologies are paving the road towards autonomous cars. Instead of revolution, fully autonomous cars—when they do arrive—will simply extend features that have already proven themselves on high-speed highways and congested city streets around the world.

And perhaps they are altering our definition of car technology, much as 007's Aston Martin did all those years ago.

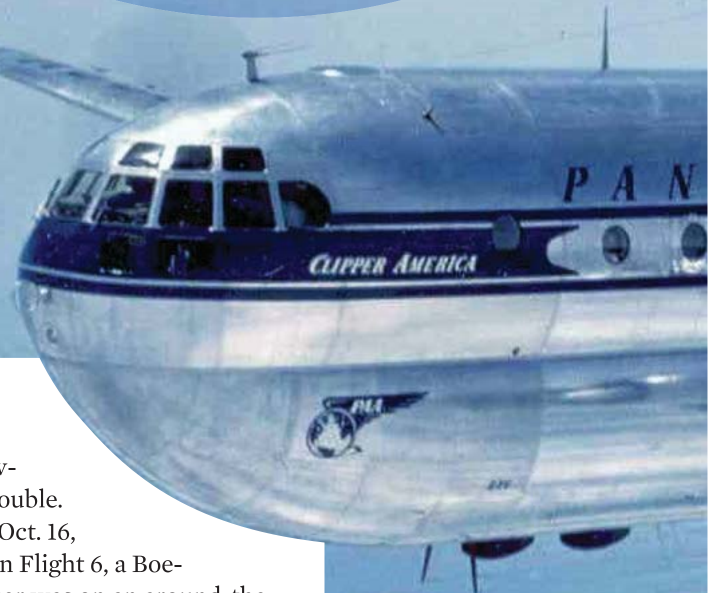
ALAN S. BROWN

F32

FORWARD

GAS TURBINES ARE CHANGING THE WORLD— IN THE AIR AND ON LAND.

BY LEE S. LANGSTON



TOO OFTEN WE TAKE FOR GRANTED THE SAFETY AND CONVENIENCE THAT MODERN TECHNOLOGY PROVIDES. We don't consider a troubled pregnancy successfully completed to be a miracle or an infected wound to be a life-threatening predicament, such is the routine excellence of medical care. Cell phones have taken a lot of the guesswork out of life—and have made the plots of many old movies obsolete.

And lest anyone doubt the efficiency and reliability of the modern commercial jet engine, we should remember that transoceanic flights which now seem almost routine were once supported with a small fleet of ships stationed in the north Atlantic and Pacific oceans.

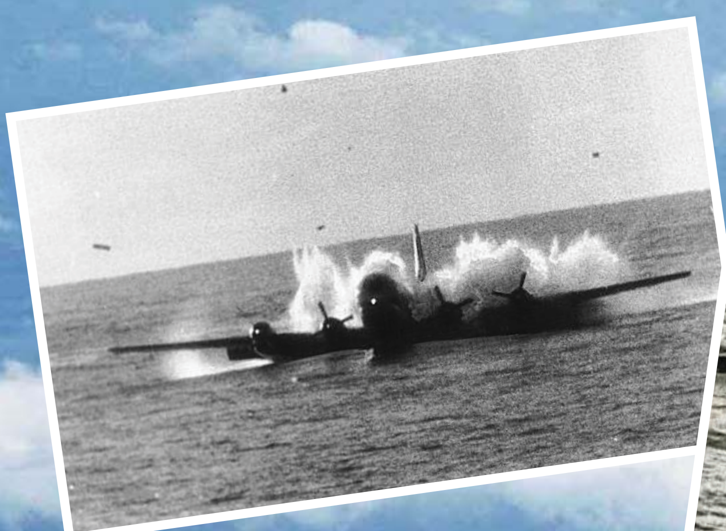
Retired airline pilot Captain Paul Eschenfelder recently reminded me of the past existence of these so-called weather ships. Eschenfelder recalled talking with Ocean Station November in the mid-1970s as the jet-powered airliner he piloted passed over the ship. (After official reporting was completed, he would read them baseball scores, a welcome message in their isolated location.)

They were positioned not only for weather reporting, but also to aid in possible search-and-rescue operations for piston-engine-powered airliners in trouble.

For instance on Oct. 16, 1956, Pan American Flight 6, a Boeing 377 Stratocruiser was on an around-the-world leg between Honolulu and San Francisco. After passing the point of equal flight time, two of the four piston engines failed and the crew was forced to ditch in the Pacific Ocean. The potential calamity was averted thanks to the U.S. Coast Guard cutter *Pontchartrain,* which was on monitoring duty at the Ocean Station November, 30° North and 140° West. All 31 crew and passengers on the plane were rescued by the *Pontchartrain*, but 44 cases of live canaries in the 377's cargo hold were lost when the plane sank.

That Pan Am Clipper was powered by four Pratt & Whitney piston engines. Although emblematic of the pioneering age of air travel, those commercial aviation piston engines were prone to failure. One gauge of that lack of reliability is that an aviation piston engine manufacturer could expect to sell 20 to 30 times the original cost of an engine in aftermarket parts.

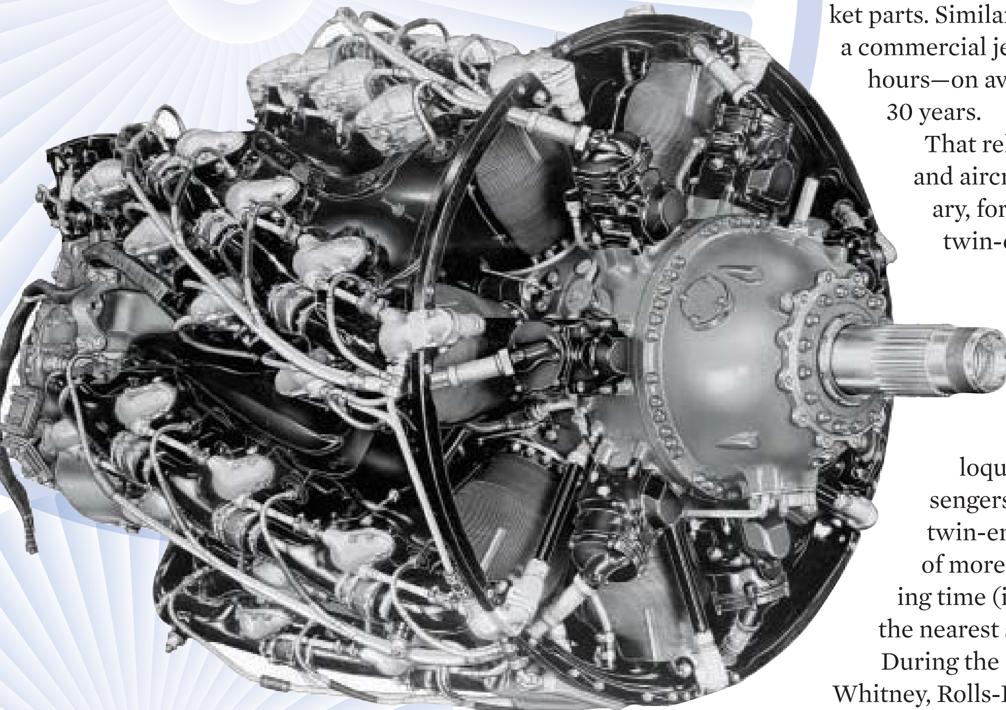
FUTURE



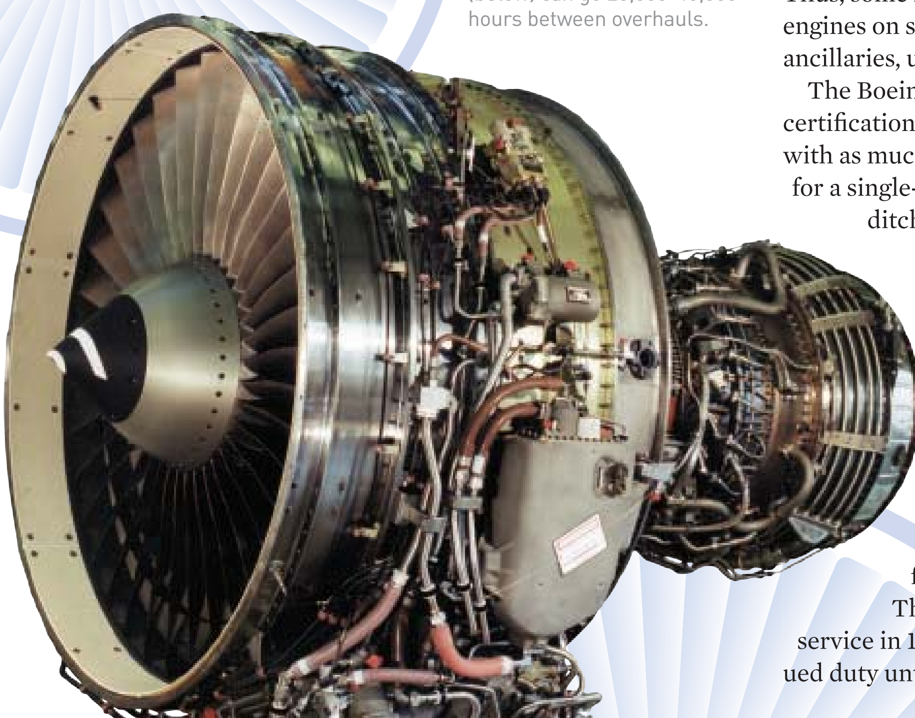
A Boeing 377 on a 1956 round-the-world flight ditched in the Pacific when two of its four engines failed. Fortunately, a U.S. Coast Guard weather ship was stationed nearby and rescued the passengers before the plane sank.
Image credit: Boeing Company (top), William Simpson, U.S. Coast Guard (insets).

By contrast, commercial jet engines require only about two to three times their initial costs in aftermarket parts. Similarly, the current inflight shutdown rate of a commercial jet engine is less than 1 per 100,000 flight hours—on average an engine fails in flight once every 30 years.

That reliability has changed the way airlines and aircraft manufacturers operate. In February, for instance, my wife, Liz, and I flew in a twin-engine Boeing 777 over open ocean on an eight-hour flight from Los Angeles to Papeete, Tahiti. The aircraft had to meet the Extended-range Twin-engine Operation Performance Standards, or ETOPS. (Engine company engineers sometimes colloquialize ETOPS to "Engines Turn or Passengers Swim.") ETOPS certification applies to twin-engine jets on routes with diversion times of more than 60 minutes for single-engine flying time (in the event of a failure of one engine) to the nearest suitable airport.



The Wasp Major R-4360 air-cooled piston engine used on the Boeing 377 (above) needed an overhaul every 1,000 hours; today, the popular CFM56 jet engine (below) can go 20,000-40,000 hours between overhauls.



During the 1990s, engine companies such as Pratt & Whitney, Rolls-Royce, and General Electric carried out extensive engine component testing to meet ETOPS certification. Operational data showed that inflight engine shutdowns were most frequently caused not by the failure of gas path components (disks, blades, and stators), but by problems with engine ancillaries such as fuel control components and exterior engine case tubing. Thus, some ETOPS test programs involved mounting engines on shaker tables, to reveal weak points in engine ancillaries, under sustained vibrational loading.

The Boeing 777 entered service in 1995 with ETOPS certification and currently can operate on some routes with as much as a five and a half hour diversion time for a single-engine flight. Remember, the Stratocruiser ditched in the ocean with two working engines.

Since aircraft operating expenses decrease by reducing the number of engines, twin-jet-engine planes have made intercontinental trijets (such as the L1011 and MD-11) obsolete, and have cut into the market for four-engine planes like the Airbus 340.

The reliability of jets and the availability of unmanned weather buoys (and later, satellites) also eliminated the need for weather ships.

The last U.S. Coast Guard weather ship left service in 1977, although one Norwegian ship continued duty until 2010.

THE TECHNOLOGICAL SUCCESS OF THE COMMERCIAL JET ENGINE has changed airline operations—and the aircraft built to serve them—in other ways. For many years, 40 to 60

The reliability of modern gas turbines enable twin engine aircraft, such as this one on final approach to Hong Kong International Airport, to operate on routes that take them more than 1,000 miles from the nearest emergency landing strip.
Image: Altair78

percent of airline operating expenses have been jet fuel costs. Airlines tried all sorts of strategies to reduce fuel costs, such as locking in prices on long-term fuel contracts as a hedge against price spikes, but they also had a keen interest in ways to reduce overall consumption.

Major engine manufacturers responded to that pressure. Both Pratt & Whitney's PW1100G geared fan engine and the LEAP 1A engine from CFM International (the joint venture of General Electric and Snecma) promise a reduction of about 15 to 18 percent in fuel consumption. The reception of these engines by the airlines has been so positive that airframe manufacturers Airbus and Boeing plan to offer essentially new versions of existing single-aisle, narrow-body aircraft that can accept the high-efficiency engines. There is even talk of Airbus launching an A380neo, a re-engined version of its wide-body, double-decker 500-passenger aircraft.

Aviation Week and Space Technology estimates that Emirates, the Dubai-based airline that's a major A380 customer, spends $40 million per year on fuel for each of its A380s. If an engine upgrade resulted in a conservatively estimated 10 percent fuel efficiency gain Emirates would get a fuel savings of about $4 million per aircraft per year, plus some maintenance cost gains that new engines bring about.

That's just part of the calculus that enters the decision-making process in what we'll call the commercial aircraft gas turbine business, the largest of the five market segments that make up the gas turbine industry.

And that business was basically at full thrust in 2014. To meet the demand for its new geared fan engine, for instance, Pratt & Whitney has installed and opened up a completely new horizontal assembly line in its Middletown, Conn., plant.

Meanwhile, CFM International delivered 1,560 CFM56 engines to airframe companies, a new annual record for this 30,000-pound thrust, top-selling aircraft jet engine. An astonishing 23,000 and change have been sold in 36 years.

Forecast International of Newtown, Conn., provides a financial picture of the gas turbine industry, its history, current state, and forecasted future. The company, using its computer and extensive data base, has computed the value of gas turbine manufacturing production from 1990 to 2014, and has projected values to 2029. (FI considers production figures to be more accurate than reported sales.)

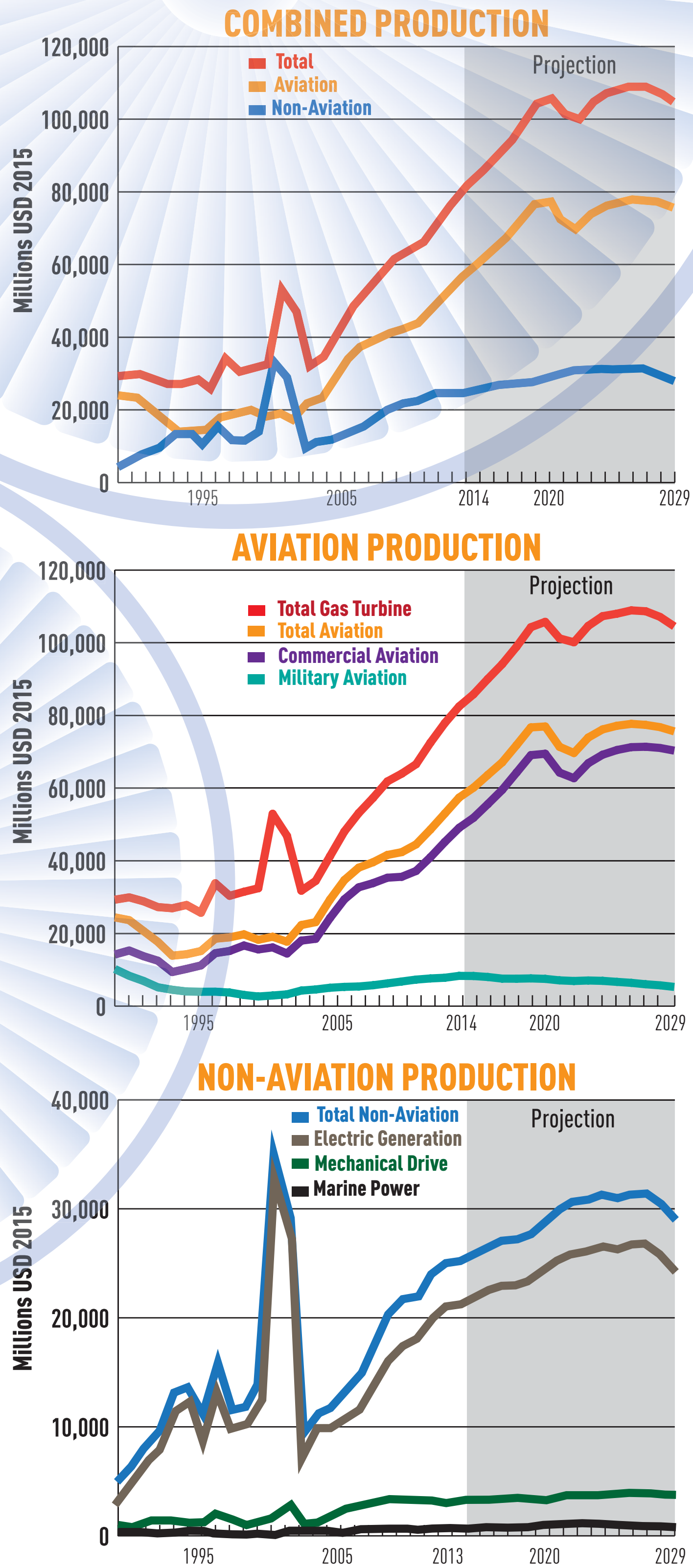
The worldwide production of gas turbines includes the commercial and military aviation markets, as well as non-aviation markets for electrical generation, marine applications, and mechanical power (mostly for driving natural gas pipeline compressors). FI's analysis shows that the value of production of gas turbines worldwide was $82.5 billion for 2014, up from $77.9 billion in 2013. FI's predictions show continued growth, with the global market increasing to $108.9 billion (in 2015 dollars) by 2026, an increase of 32 percent over 2014.

Aviation gas turbines make up the largest segment, totaling $57.4 billion last year, which represents about 70 percent of the gas turbine market. Within the total aviation market, engines for commercial aircraft accounted for 85 percent, with a 2014 total value of production of $49.1 billion. The remaining $8.3 billion of production was intended for military aircraft, such as the Lockheed Martin F-35 Joint Strike Fighter and the Boeing C-17.

The non-aviation gas turbine market, with a

GAS TURBINE INDUSTRY 1990 - 2029
(VALUE OF PRODUCTION)

Data from Forecast International shows a rapid increase in production of commercial airline engines and gas turbines intended for electrical generation.



value of production for 2014 of $25.1 billion, is characterized by a particular vitality—and volatility.

Utility electrical power gas turbines make up by far the largest portion of the non-aviation market, some $21.1 billion last year. As FI's value-of-production history shows, the electric power gas turbine market had one wild swing in 1999-2002 when electrical utility deregulation caused a short-lived fever in gas turbine power plant construction. Since then, the market has shown a steady recovery, with FI predicting a value of production of $26.7 billion in 2027, though that will still be below the irrational exuberant peak (in 2015 dollars) of $31.8 billion in 2001.

Mechanical drive gas turbines had a value of production of $3.2 billion in 2014, and FI expects this to hold steady in the future, relying on the continuing need for natural gas line compressors and the growing need for liquefied natural gas plants in which gas turbines power the LNG trains. Non-aviation marine power gas turbines had a value of production of $0.8 billion, a small but fairly steady share of the market.

IN RECENT YEARS, GAS TURBINE COMBINED-CYCLE PLANTS have become key players in the generation of electric power. In combined-cycle plants, heat from the hot gas turbine exhaust enters a heat recovery steam generator (or boiler) to generate steam for a steam turbine, used to generate more electrical power. Thus, one unit of fuel—usually natural gas—goes into the gas turbine combustor, to supply two sources of electrical power.

These combined-cycle plants (the largest are in the 600-700 MW range with gas turbines producing 400-500 MW) have thermal efficiencies that are now exceeding 60 percent, making these the most efficient energy converters mankind has perfected. Additionally, their capital costs are lower than pure steam power plants and far less than nuclear. Now shale gas finds in the U.S., made accessible by hydraulic fracturing and new drilling techniques, have dropped the price of natural gas fuel to low levels comparable to coal.

The U.S. Energy Information Administration recently calculated the levelized cost of these new combined-cycle plants, compared to coal and nuclear. (Levelized cost represents the per-kilowatt-hour cost of building and operating a generating plant over an assumed financial life and duty cycle.) The EIA reported that new gas turbine combined-cycle plants come in as low as 6.3 cents/kWh, some 43 percent lower than nuclear and 36 percent lower than a coal-fired plant. Some in the power industry complain about the so-called War on Coal or War on Nuclear, but if those industries are under siege, it is from the high efficiency and low cost of these gas-fired combined-cycle plants.

TODAY, THE ORIGINAL EQUIPMENT MANUFACTURERS WHO supply large gas turbine combined-cycle plants are General Electric, Siemens, Mitsubishi, and Alstom. And soon, the industry will be consolidated further, as GE is in the process of acquiring the power segment of Alstom, thus narrowing the field of large plant OEMs to a Big Three—similar to the threesome in aviation: GE, Rolls-Royce, and Pratt & Whitney—with GE in the lead.

It wasn't always thus. In the 1970s, the electric gas turbine market was smaller and there were more OEMs, which have been sorted out as efficiencies increased and natural gas prices decreased.

One OEM that dropped out of the electric market was Pratt & Whitney. In the early 1970s, the company's management decided to use the P&W jet engine design system to develop a new efficient heavy frame 100 MW electric power gas turbine.

At the time, advances in jet engine design hadn't been extensively incorporated into the design systems of the non-aviation OEMs. For instance, General Electric had a then-current corporate policy encouraging its Schenectady-based non-aero Power Generation Group (producing a Frame 10 series in the 100 MW range) to compete with GE's own Evandale, Ohio, Aircraft Engine Group's aeroderivative engines, used for non-aviation applications.

Pratt's heavy frame engine was called the FT50 and it hit a record (for the time) 34 percent thermal efficiency with its jet engine design gas path. As a young engineer with P&W in 1975, I saw the 36-foot-long FT50 on the assembly floor in the Middletown plant—easy to pick out, as it overshadowed collections of jet engines in surrounding areas. Shortly thereafter the company's management decided to end the multi-million dollar FT50 program it had been partnering with the Swedish company, Stal-Laval. Only one of the engines had been completed.

Hindsight shows that the FT50 was technically well ahead of its time—and competitors. Using Pratt's experience from military jet engines, the FT50 had the first use of non-aviation turbine film cooling. That allowed it to run at turbine inlet temperatures of 2,100 °F, much higher than contemporary machines and contributing to its record-breaking 34 percent thermal efficiency.

The FT50 also had Pratt's twin spool design, allowing each compressor and turbine to operate at optimum component efficiency. (Compressor efficiencies were 90 percent—higher than any other non-aviation gas turbine at the time.) And following aviation gas turbine design, the FT50 was constructed in modular form, which enabled the engine to be easily dismantled in days rather than the standard several months, for say, combustor replacement.

The Pratt & Whitney FT50, on the assembly floor in Middletown, Conn., in 1975. The turbine is being installed in Angola. *Image: Don Cleary*

Counterfactuals are always impossible to prove, but had Pratt & Whitney not abandoned its multimillion dollar investment in the 1970s, it might today be one of the Big Three in both the aviation and non-aviation market segments.

Last September I gave a talk at the Stal-Laval plant (now part of Siemens Industrial Turbomachinery) in Finspång, Sweden. There I learned that the sole FT50 gas turbine ever manufactured had been sold to a Swedish utility and had been in operation since the late 1970s. Indeed, it had only recently been decommissioned.

But that wasn't the end for the FT50. The unit, now about 40 years old, is being installed at a plant in Angola for further electrical generation.

In most cases, sure, new is usually better. But when a piece of technology is well designed and built to last, it can endure and find new uses over and over again. **ME**

LEE S. LANGSTON is an ASME Fellow and professor emeritus of the mechanical engineering department at the University of Connecticut in Storrs.

WORK BUDDIES

Because of their low cost and flexibility, a new generation of robots has begun to show up on the shop floor. Will they soon begin to collaborate with human workers?

BY ALAN S. BROWN

Rethink Robotic's Baxter (above) and Universal Robots' UR3, rated for 3 kg loads, (right) are two next-generation "inherently safe" robots able to work near people.

Hand-held controls help workers teach robots new tasks.

WALKING THROUGH A LARGE AUTOMOBILE FACTORY IS LIKE PASSING between two worlds. On one side, powerful robots rapidly position and weld sheet metal into framed car bodies. On the other, thousands of workers add doors and other moving parts, power systems, chassis subassemblies, and trim.

That division is there for a reason. Up to now, industrial robots have been big, fast, dangerous, and dumb. They have to be kept in cages and away from people. The danger has limited their uses among workers on assembly lines.

An emerging generation of robots is promising to change all that. They can be let out of the cage. They are nimbler, easier to program, and far less dangerous.

These collaborative robots—designed to work safely with and around people—combine low cost and ease of use. They are finding their way into large plants and also into small factories, which can now automate batch runs that would never be economical with a conventional industrial robot.

Like the first PCs, this new generation of robots is a general solution. Engineers do not have to redesign their entire assembly line to use them. As a result, they can apply them in many different ways.

For instance, Glidewell Laboratories of Newport Beach, Calif., used a robot to reconfigure its manufacturing process.

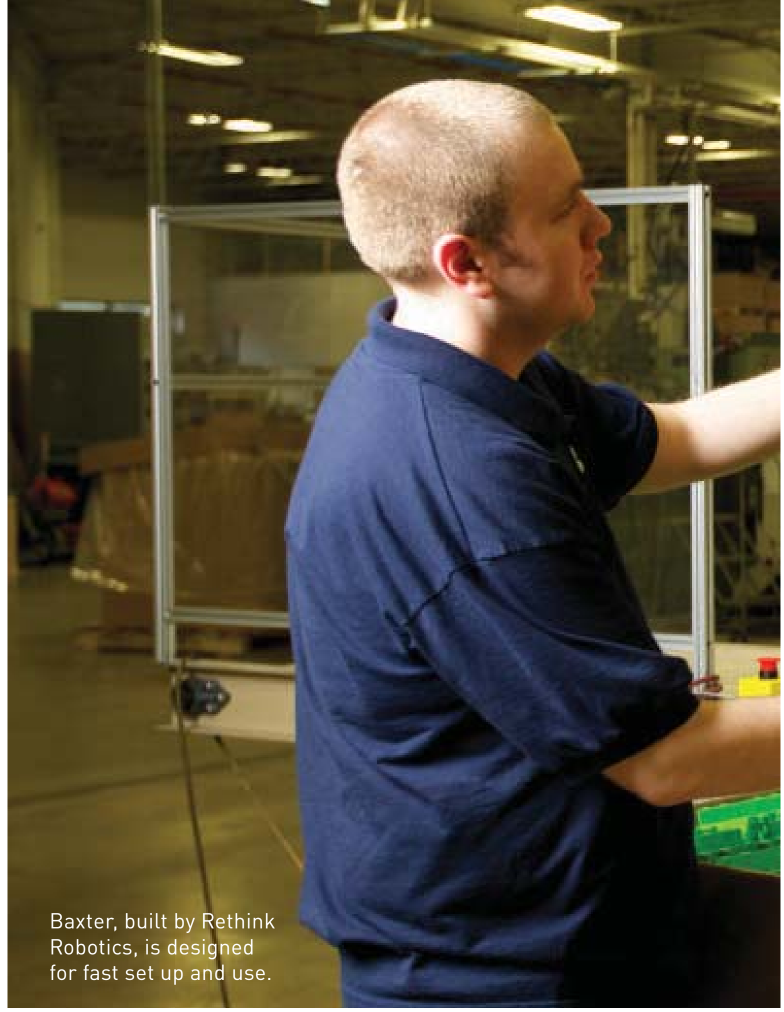
Glidewell is a large producer of dental crowns from impressions of patient's teeth. Every crown is a custom order, and the workflow was almost artisanal in its many manual steps. Over the past few years, however, Glidewell has added engineering software and automation to improve productivity. Robots were the next logical move, and Glidewell had an obvious application.

"We're making 30,000 zirconia crowns per week, and it's really hard to keep up when you're making a custom product," said David Leeson, Glidewell's engineering manager.

It takes several steps to make a crown that matches a patient's tooth shape and color. When the company receives an impression from a dentist, it casts a replica of the patient's mouth and scans it into a 3-D CAD file. Glidewell designs the crown in CAD and sends the output to a CNC mill for machining.

Before installing the robot, Glidewell put each replica into a case box and sent it to the mill. It took the mill about 10 minutes to shape each crown. Rather than have an operator

Precise Automation makes the PF400, a collaborative SCARA robot shown servicing laboratory equipment.



Baxter, built by Rethink Robotics, is designed for fast set up and use.

standing around waiting, it made sense to machine 15 crowns at a time from a single disc of compressed zirconia powders.

Once the boxes arrived at the mill, the operator would group the molds by size and color to optimize material utilization. He also had to record the location of each crown on the disc, and this manual process sometimes led to errors.

These manual processes created a logjam at the mill. Leeson broke it by using a collaborative Universal Robotics UR5 robot to tend four CNC mills. The robot made it economical to switch from processing a batch of 15 crowns to milling a single crown at a time. Now, CAD models go directly to the mill. Instead of waiting until the operator has enough molds to sort and group, the robot matches the colored blank and begins machining.

> **"People around it feel safer because the robot slows down when they come near."**
> **— Jean-Francois Rousseau, plant engineer at Etalex**

"This gives us single part flow," Leeson said. "It used to take three hours for the cases to go from design into the mill. Now the CAD data transfer is instantaneous."

The system also improves quality. Instead of having the operator manually record the position of each crown on the disc, the robot, working with Glidewell's manufacturing information system, matches the crown preform with the CAD model and records its location when placed into a barcoded tray for sintering into a final crown.

"We get way fewer returns now," Leeson said.

So far, this could be a story about any industrial robot. In fact, Glidewell also uses a conventional robot in another part of the plant.

"The big difference between that robot and the Universal is that the conventional robot is caged and requires a constant level of engineering support," Leeson said.

LIMITED FORCE

Eliminating the cage simplifies layout and workflow. Conventional robots are caged because they are dangerous. They are fast and powerful, and most have no way to detect collisions with anything short of a large hunk of metal.

The UR5 is a power- and force-limiting robot, one that operates at low speeds and light payloads. With dual sensors in every joint, the robot stops within milliseconds of the slightest impact. At worst, it delivers a modest shove. Workers can safely deliver new zirconia blanks and remove milled parts without stopping the robot and losing time.

The UR5 is also easy to use, Leeson said. It includes features, such as Ethernet connectivity, that cost extra on conventional robots. He said the user interface is easy for anyone with programming or engineering skills to learn, and it comes with a simulator to test scripts.

Above all, the UR5 is flexible. Like a PC, it is a general-purpose device that does a variety of tasks. Leeson, for example, used it as an alternative to dedicated automation. He estimated that it would cost about $150,000 to automate the Glidewell's zirconia crown work cell. The UR5, including modifications, programming, and setup time, cost little more than one-third of that. The savings alone would fund roughly

two more robotic work cells.

As robotics technology has matured, programming robots (and just about everything else) has grown easier and more intuitive. Key components, such as motion and impact sensors and vision systems, combine better performance with costs low enough to sell in cheap video game controllers.

The result is a change in the robot paradigm. The installed cost of a typical industrial robot is two to three times the robot price. New-generation robots generally cost far less, \$20,000 to \$40,000, and as Leeson noted, cost far less to install. Universal and another manufacturer of safer industrial robots, Rethink Robotics, founded by Rodney Brooks, the inventor of the Roomba, claim most customers earn back the investment in their robots in six to nine months.

The UR5 was Universal Robots' first model, introduced in 2009. The company was the first manufacturer to claim its industrial robots were inherently safe because they limited their power, force, and speed. Other power- and force-limiting robots today include Rethink Robotics' Baxter, ABB's Yumi, KUKA's LBR iiwa, and Precise Automation's line of articulated, SCARA, and Cartesian robots.

Most of these robots are similar to conventional industrial robots, but are smaller, lighter, and simpler to use. They carry small payloads, usually 3 to 10 kg, at relatively low speeds. They also contain sensors sensitive enough to detect a low-speed collision and fast pathways that stop motion within milliseconds. This reduces the likelihood of injury if they hit a worker.

They are also easy to use. Programming, for example, involves moving the robot arm between points to teach it a job, then using code to refine the task and tell the grippers or other end effectors what to do.

The robots are easy to program for simple tasks, such as pick and place, machine tending, and product testing. Precise Automation specializes in moving laboratory samples.

UNCAGED IN TIGHT SPACES

Because they can work uncaged around people, power- and force-limiting robots can function where space is limited and must be shared. That ability solved a dilemma faced by Jean-Francois Rousseau, a plant engineer at Etalex, a Montreal-based manufacturer of steel storage systems.

Rousseau had a huge metal punch located at the front of his plant. Removing punched metal is dangerous work, and he wanted to automate the process. The 12-foot-long punch, however, was only six feet from the main aisle.

"We didn't have any space to put in a safety guard, and forklifts and employees pass down that aisle all day long. And we didn't want to move the press, because it is such a big setup," Rousseau said.

He turned to Universal because it was similar to the 30 Fanuc industrial robots he already managed, and he liked its smooth motion and precision. Rousseau handed the programming over to a junior engineer. Within a month, the robot was removing and stacking long bent strips of metal as they come out of the punch.

The robot works largely on its own. Workers periodically enter the space to measure a part and remove carts of stacked parts. A laser scanner senses when workers approach and slows the robot down by 30 percent.

"People around it feel safer because the robot slows down when they come near," Rousseau said.

Eliminating fences also makes it easier to change tooling. With conventional robots, Rousseau would have to remove the fence and robot to get a forklift carrying the massive tooling through. Now, he unlatches a bracket and slides the robot out of the way to access the center of the press.

In most factories, the only difference between power- and force-limiting robots and conventional industrial robots is the absence of fences. With Baxter (and its new Sawyer robot for machine tending), Rethink Robotics hopes to bring greater flexibility to the shop floor.

"We designed it to roll the robot off, train it easily, and change tasks from month to month," said Rethink product manager Brian Benoit.

Baxter comes with several innovative features. One is the robot positioning system. By using a camera embedded in its wrist, it can orient itself by locating markers posted around the workspace.

"Now you can design tasks in two different cells, turn on the positioning system, and the robot will orient itself and get right to work," Benoit said.

Baxter also has what Benoit calls "adjustable behavior."

"Baxter knows where the part is in the work cell, and knows if it is holding a piece or misses a pick," Benoit said. "It won't just continue with the process. It will pick up the part or repack it again. It has sensors on board that make it possible to put these behaviors in place."

Unlike most robots, whose joints use gear boxes with hard stops, Baxter has elastic actuators. They make it slightly compliant. If its arm bumps into someone, it gives a little bit.

That gives Baxter an extra margin of safety. Compliance, when coupled with built-in force sensitivity, also lets Baxter perform more tasks. It could, for example, test a circuit board. This usually involves inserting the tester guide pin through a hole on the board.

> **"We designed it to roll the robot off, train it easily, and change tasks from month to month."**
> **— Brian Benoit, Rethink product manager**

"A human would use the guide pin to feel his way in and give it a shake to mount it," Benoit said. "A typical robot would have to go top down. Baxter comes in at an angle, like a person, and when it feels the force feedback, it has another move that seats it."

At Du-Co Ceramics in Saxonburg, Pa., process engineer Josh Rupp is taking advantage of Baxter's flexibility to add automation to short production runs.

Du-Co created a small work cell with a simple conveying system. Ceramic preforms come down the line, one at a time and oriented in the same direction. When they arrive at a known location, the system controller tells Baxter to pick them up. The robot then places them in trays for sintering. Workers periodically enter to deliver empty trays and remove full ones.

"We can look at production runs we could never automate before, because the time required to set up the work cell wouldn't have justified it. In the past, we would have done it with people. Now, we can create a versatile cell that we can move from machine to machine," Rupp said.

As with other power- and force-limiting robots, programming was simple. In fact, Rupp hopes he can eventually train workers to set up Baxter.

"That's the best way to utilize its flexibility," Rupp said.

EMERGING SAFETY STANDARD

While power- and force-limiting robots have many boosters, their payloads are limited. At most, they might lift 14 kilograms. That's a problem for companies that work with large or heavy parts.

General Motors' principal robot engineer, Marty Linn, sums it up succinctly: "Inflatable hammers are inherently safe, but not very good at pounding in nails."

That is why engineers are developing ways to instrument conventional industrial robots to work safely near humans. A new standard under development, ISO 15066, *Safety Requirements for Industrial Robots—Collaborative Operation*, outlines four distinct safety strategies.

One, of course, is limiting power and force. The second is the safety-rated monitored stop, where the robot stops as soon as a worker triggers a sensor (such as a light curtain or pressure mat) by walking into its space. It resumes work once the human leaves.

Third is hand guiding, which allows humans to teach an arm a new set of motions while it is in live automatic mode.

Fourth is speed and separation monitoring, which uses sensors to track workers and to slow or stop the robot if humans get too close.

Many industrial robots are already equipped with these safety-rated sensors.

"The major industrial robot makers have been doing functional safety for more than four years," said Erik Nieves, technology director for Yaskawa Motoman.

Those robots could be used in collaborative applications once ISO 15066 is adapted, he added.

In fact, some companies are already using industrial robots collaboratively. Nieves described one customer that uses a worker-robot team to move 400-pound castings.

"The robot can't pick up the parts blind, because they are unwieldy and come on a pallet in a variety of positions," Nieves said. "The robot has an autonomous program and moves where the part ought to be, then waits for the operator to move the robot into position to pick it up.

″After the operator walks out of cell, the robot resumes the

Heavy robot in a fenced-in enclosure at the General Motors Fairfax Assembly Plant.
Image:Susan McSpadden/Chevrolet

autonomous part of the work."

GM's Linn would like to put collaborative robots on his assembly lines, especially in tasks that are dull, dirty, or dangerous for humans. He is intrigued with BMW's demonstration of a robot that can glue a water deflector to the side of a door using constant pressure, a job that he calls "ergonomically challenging" for workers.

Yet, after GM's experience with recalls last year, the company has doubled down on safety throughout the organization. GM will not consider collaborative robots without third-party safety certification to internationally recognized standards and specifications.

The lack of existing safety standards leads Linn to question the safety of "inherently safe" robots. It depends on the jobs and the individuals, he argues. Bumping into someone with a 5 kilogram load might not hurt, but a lighter metal sheet with a sharp edge could slash through skin.

Researchers at Germany's University of Mainz are trying to answer those questions through a research program that evaluates pain and injury thresholds. The work is complex, and has slowed the adoption of ISO's collaborative robot standard. Linn is not happy about it.

"Without clarity there, it handcuffs us quite a bit," he said. "Our company believes in standards. If you go to any trade show, robot manufacturers are all working on something, but to be very candid, they have not gotten to the level of certification we need."

Nor are collaborative robots very collaborative. In fact, most simply coexist with humans. They modify their behavior when humans enter or leave their space. Perhaps one day soon they can do kitting, grouping parts from bins so a worker can install them. Still, that is about as far as the present generation is likely to go.

Researchers, such as Aaron Bobick, who founded Georgia Tech's School of Interactive Computing, and Julie Shah, who heads MIT's Interactive Computer Group, hope to change that.

Bobick, for example, has trained robots to know a task's sequence, so they can then take the right actions at the right time. Shah, meanwhile, has focused on teaching robots to anticipate and respond to human actions.

"Robots use repetitive motion, but people don't," Shah said. "People go a little faster or slower. That means the robot is starting and stopping a lot, and we lose the economic benefit of automation if it does that."

Those advances are still years away. Today's robots may not be very interactive, but neither were the first PCs. It took years for today's intuitive interfaces, Internet, and smartphones to evolve. Yet even in their earliest forms, PCs made it easier to perform some tasks, like creating spreadsheets or writing and revising documents. Similarly, the first wave of collaborative robots are finding simple tasks where they can make a difference.

On the shop floor, the revolution is only beginning.

ALAN S. BROWN is associate editor of *Mechanical Engineering.*

Laboratories of Policy

I remember being fascinated by Washington, D.C., from my first visit. The White House and Capitol Building weren't just symbols but the seat of power for the greatest country in the world. The decisions and laws made in those buildings didn't only affect us as Americans, but had an impact on the entire civilization. During one of my trips, I realized that I wanted to come back someday and participate in lawmaking.

I returned in 2013 not as a visitor, but as a Science and Technology Policy Fellow, part of the ASME Congressional Fellows program. To be accepted for the program was a great honor, I knew, but what I didn't realize in advance was the way that having a trained engineer on a congressional staff could have an important and long-lasting impact on public policy. I thought I would be one of many people trained in the physical sciences helping shape complex technical policy; too often, I was pretty much the only one.

Indeed, what I took home from my year in Washington was not a wonder at the magic of self-government but a realization that engineers and other scientifically trained individuals are not doing enough to influence policy.

So many public policy issues deal with questions that have a science or engineering basis, and those issues are being decided in many cases without an understanding of what is at stake. For instance, during the 113th Congress, which met in 2013 and 2014, only 12 House and Senate members had engineering degrees. A mere 5 to 10 percent of the Congres-

Engineers cannot remain outside the political process. Their expertise is needed to ensure that technical policy is crafted to do the most good.

By Bharat Bhushan

sional staff who prepare the legislation typically possess physical science or engineering degrees. And at the state level, the numbers are no better.

Engineers could bring a perspective that is too often not considered in the halls of Congress. Too often, we hang back and let important decisions get made by people who don't really understand scientific and engineering principles behind the policy they are deciding.

WASHINGTON AT WORK

For my fellowship, I was assigned to the Subcommittee on Research and Technology of the House Committee on Science, Space, and Technology. Given my academic background and major focus on nanotechnology, the subcommittee seemed to be the most appropriate training ground and the best opportunity to contribute. Not only is the Subcommittee on Research and Technology responsible for funding for the National Science Foundation and the National Institute of Standards and Technology, as well as other technology agencies and science education programs, but it is also responsible for 21st Century Nanotechnology R&D Reauthorization Act. I approached the chair of the committee and let him know about my expertise; they were keen on having me there.

One of my duties was to prepare the subcommittee for hearings on major bills. For instance, I worked on the preparations for a May 2014 hearing to be titled, "Nanotechnology: From Laborato-

Leading the House: During his year as a Congressional Fellow, Bhushan met and worked with such national figures as (from top) Speaker of the House John Boehner of Ohio, Minority Leader Nancy Pelosi of California, and Chairman of the House Science Committee Lamar Smith of Texas.

ries to Commercial Products." That was a topic dear to my heart, as I have spent a good portion of my research career studying nanoscale phenomena.

It turned out that the 21st Century Nanotechnology Research and Development Act hadn't been reauthorized since 2007, so I prepared a background paper on the technology and prepared critiques on all reviews mandated by Congress on the National Nanotechnology Initiative. And I stressed the need for a set of informational hearings to be followed by enactment of a nanotechnology research and development reauthorization act.

To bolster that case, I prepared a detailed summary of every college and university that awarded degrees in nanotechnology, of public and private R&D funding and capital investments, and of the number of nanotechnology companies, with annual output in dollars and number of jobs created, in districts of all Congressmen on the committee on both sides of the aisle. The purpose was to stress upon committee members that their districts benefited from the nanotechnology field and they needed to be engaged and be supportive.

The logistics involved in holding a hearing can be daunting. I needed to select potential witnesses for the hearing who would provide an expertise in the field, while not neglecting to include one each from the districts of the chairs of both the full committee and subcommittee.

I prepared a hearing request, which had to be approved by the committee chair, and then I prepared a hearing charter to schedule a hearing. Just before the hearing, I helped prepare the hearing documents to be used by my committee with a long list of potential questions.

It wasn't only hearings; I assisted in the preparation of legislation. Unlike the process that's taught in civics classes, the route that most bills take to become law is a tortuous one. To be sure, the path a bill takes includes hearings and mark-ups by the relevant committee, followed by a series of votes in the House and Senate, and if passed using identical language in both houses, then it has to be signed by the president.

But bills are also shaped by lobbyists and stakehold-

We can lobby legislators in favor of policies, educate our fellow citizens on the engineering view of issues—or even run for office.

ers, and get tainted by the political process. The legislators have constituents to please, and a party platform to observe.

As most people realize, the political climate while I was fellow was not conducive toward passing new laws and regulations. The partisan divide was almost unbridgeable. The 110th Congress saw nearly 14,000 pieces of legislation proposed, and about 97 percent were rejected.

But in my time on the subcommittee staff, I was able to see a few landmark pieces of legislation through the committee. For instance, I participated in the putting together of the Frontiers in Innovative Research, Science, and Technology Act, intended to reauthorize funding for various science agencies and programs. In the process, we had to not only develop the legal document, but also negotiate details with various committee members and their staffs, and to continuously seek critiques from inside and outside. And, surprising to me, there were many hearings: ones to introduce the bill, which involved external witnesses, and mark-up hearings organized by the subcommittee and the full committee, for which we prepared responses to proposed amendments.

I also worked on the Revitalize American Manufacturing and Innovation Act of 2013, which provides funding for establishing national networks for manufacturing innovation in targeted areas, and the STEM Education Act of 2014, which provides funding to promote STEM education at all levels, from kindergarten through college, with some focus on economically disadvantaged and minorities.

ENGAGING THE PUBLIC

My time as a Congressional Fellow was a life-changing experience. But let's face it: there are not enough staff positions in Washington for every engineer to become engaged in policy through that sort of program. I believe it is critical that engineers find a way to become involved with policy making, so it's important to find ways of doing that closer to home.

Back home in Columbus, for instance, my colleagues and I have created an undergraduate minor in science, engineering, and public policy, a joint program between the College of Engineering and the John Glenn College of Public Affairs at my university. I have been appointed an affiliated faculty member in public affairs and champion the engagement of engineers in public policy at every opportunity. I am giving lectures in a cross-listed course on science and public policy. And I am ready to give talks at other colleges and universities about this and the importance of federal R&D investment, a policy on which I feel strongly.

This sort of engagement can make up for the lack of science and technology literacy among legislators, especially at the state and local levels. There are many ways that engineers can get involved, including directly, by taking up positions on the staff of state or federal representatives—or even by running for office themselves. We can lobby legislators in favor of policies and educate our fellow citizens on the engineering view of issues.

Above all, we must gain the training and experience needed to reach out to the public, both in speaking skills and in writing for a general audience.

There is a longstanding bias among engineers against engaging in public policy debates. We tend to let our research and products do the talking for us. But to me, this approach is mistaken. More than ever before, engineers need to be in policy making or aggressively engage their policy makers. Those of us in academia need to develop minors and develop cross-listed courses on science and public policy. This would provide a window to students on public policy and some may take a path of public policy either full time or in an advisory capacity at some point in their careers.

Engineers have to be champions for pro-science and pro-technology policies. They have the knowledge, passion, and drive to encourage state and federal lawmakers to implement these policies. We would be shirking our professional and social responsibilities if we did not participate to the fullest extent.

BHARAT BHUSHAN is Ohio Eminent Scholar and Howard D. Winbigler Professor in Engineering at the Ohio State University in Columbus. Bhushan is also a Fellow and Life Member of ASME. He was an ASME Science and Technology Policy Fellow from September 2013 to September 2014.

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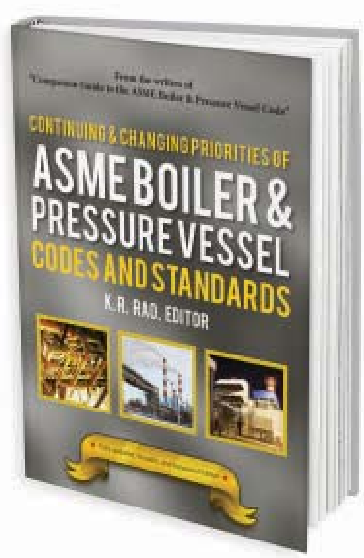

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A forum for emerging systems and control technologies.

DYNAMIC SYSTEMS & CONTROL

JUNE 2015 VOL. 3 NO. 2

HUMANOID ROBOTS

WORKING SIDE BY SIDE WITH HUMANS

ASME

SUBMIT ARTICLE IDEAS TO:

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Future issues of *Dynamic Systems & Control Magazine* will include the following themes:

September 2015
Surgical Robotics

December 2015
Automotive Powertrain Control

Humanoid Robots

Humanoid robotics is a challenging research field with very ambitious goals for the near future. Over the past decade, considerable progress has been made in the design of humanoid control systems, culminating in a number of humanoid robots with the ability to perform well-designed whole-body tasks. Nevertheless, there are still many difficult problems to be solved before robust locomotion and manipulation can be achieved, especially in highly unstructured and cluttered environments.

Humanoids have received significant attention recently and will continue to play a central role in robotics research, potentially leading to significant applications in the 21st century. As a point of reference, the official RoboCup website predicts that, "By the middle of the 21st century, a team of fully autonomous humanoid robot soccer players shall win a soccer game, complying with the official rules of FIFA, against the winner of the most recent World Cup." In June, the final competition for the DARPA Robotic Challenge will take place (the results should be announced by the time you read this). The competition will feature 25 teams from around the world working to develop robots capable of assisting human responders in natural and man-made disasters. Participating teams are collaborating to develop the hardware, software, and human-machine interfaces that will enable their robots to complete a series of challenge tasks selected by DARPA, each relevant to disaster response applications. The ability to navigate man-made environments and use human tools could provide a unique advantage to humanoid robots in such scenarios. Several teams, but not all, have been provided with a standard robotic hardware platform developed by Boston Dynamics, a humanoid robot called Atlas (depicted on the cover photo).

This issue of the *Dynamic Systems and Control Magazine* provides a sample of the challenges that researchers in this area are facing, including a few examples of how they are addressing them. In the first article, Luis Sentis introduces his vision of robotic systems for the assistance and augmentation of humans with the goal of improving our quality of life. One particular application he addresses in his article is robotic firefighting. He discusses how his Whole-Body Operational Space Control approach can be used to achieve real-time, simultaneous control of motion and force-based tasks for humanoid robots. The second article, by Christian Ott and coauthors, describes the challenges in developing safe and robust humanoid robots capable of performing complex tasks including, but not limited to, service robotics, search and rescue, and medical robotics. Their approach is characterized by the implementation of torque-controlled actuators that utilize a feedback loop to mimic the compliant behavior of human muscles. The third article, by Michael Hopkins, Robert Griffin, and Alexander Leonessa, focuses specifically on humanoid locomotion. The article discusses the benefits of introducing mechanical compliance using Series Elastic Actuators (SEAs) and the implementation of model-based control strategies for force-controllable hardware platforms. The fourth and final article, by Taskin Padir, Michael Gennert and Chris Atkeson, provides some insight into the challenges they are facing working with the Atlas platform towards the completion of the DARPA Robotic Challenge. A particular focus is given to the implementation of a human-robot interface designed to minimize human errors while maximizing the technical capabilities of the human-robot team.

I'm grateful to Michael Hopkins, who helped identify the authors in this feature section.

If you have any ideas for future issues of this magazine, please contact the Editor, Peter Meckl **(meckl@purdue.edu)**.

Alexander Leonessa, PhD
Guest Editor, *DSC Magazine*

Calls for Nominations and Manuscripts

CALL FOR NOMINATIONS:

Nominations are invited for the *2015 ASME DSCD Best Conference Paper on Mechatronics*, and *2015 ASME DSCD Best Student Paper on Mechatronics*. Nominations, consisting of the nominating letter and the nominated paper in its published form in PDF, should be emailed to Professor Xiaobo Tan (xbtan@msu.edu), Chair of Awards Committee, ASME DSCD Technical Committee on Mechatronics. The awards will be presented at the DSCD Division Meeting during the 2015 Dynamic Systems and Control Conference that will be held in Columbus, OH, October 28-30. **Nominations are due on June 30, 2015.** Nominators are encouraged to contact Professor Tan for details.

CALL FOR PAPERS:

Led by guest editor Hashem Ashrafiuon (Villanova University), guest co-editor Xiaopeng Zhao (University of Tennessee) and journal editor Joseph J. Beaman (University of Texas), contributions are invited to the special issue on *Biomedical Sensing, Dynamics, and Control for Diagnostics, Treatment, and Rehabilitation* to be published in the ASME *Journal of Dynamic Systems, Measurement and Control* in April 2016. **Submission Deadline: October 5, 2015.** Please contact Professor Ashrafiuon at hashem.ashrafiuon@villanova.edu for further details.

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ASME DYNAMIC SYSTEMS AND CONTROL DIVISION (DSCD) MEMBER NEWS


UNIVERSITY OF NEWCASTLE, AUSTRALIA

DSCD member **Reza Moheimani** was presented the Nathaniel B. Nichols Medal at the 2014 IFAC World Congress. The award letter reads "*For fundamental contributions in systems science and control theory of direct relevance to engineering practice in high precision mechatronic systems.*"

The Nathaniel B. Nichols Medal is one of the two highest recognitions bestowed by IFAC (the Quazza medal being the other one). Named after Nathaniel Nichols, one of the pioneers of control engineering, the medal was created to recognize outstanding contributions of an individual to design methods, software tools and instrumentation, or to significant projects resulting in major applications and advancement of control education.

Moheimani is the James von Ehr Distinguished Chair in Science and Technology, at the Department of Mechanical Engineering at the University of Texas at Dallas.


NORTHEASTERN UNIVERSITY

DSCD member **Nader Jalili** has been recognized for his sustained high-quality teaching accomplishments over the years, with a 2015 Northeastern University (NU) Excellence in Teaching Award. This is one of the university's highest honors, and is only awarded to the most accomplished members of NU community. Jalili is a professor at the Department of Mechanical and Industrial Engineering at Northeastern University.


UNIVERSITY OF MINNESOTA

DSCD member **Zongxuan Sun** receives the Charles E. Bowers Faculty Teaching Award from the College of Science and Engineering, University of Minnesota, where he is an associate professor.


MICHIGAN STATE UNIVERSITY

DSCD members **Zongxuan Sun** from University of Minnesota and **George Zhu** from Michigan State University published a book with CRC press entitled *Design and Control of Automotive Propulsion Systems*. The book covers all major propulsion system components, from internal combustion engines to transmissions and hybrid powertrains.

News contents edited by Rifat Sipahi.

WHOLE-BODY OPERATIONAL SPACE CONTROL FOR LOCOMOTION AND MANIPULATION

BY LUIS SENTIS, PH.D.
HUMAN CENTERED ROBOTICS LAB,
THE UNIVERSITY OF TEXAS AT AUSTIN

In [Fingar, 2008], the US National Intelligence Council reported six potentially disruptive technologies for the year 2025, one of them being service robotics. The report states that, "[...] robots for elder care applications and the development of human augmentation technologies, mean that robots could be working alongside humans in looking after and rehabilitating people." On a related note, the European company Fatronik published a study [Eizmendi, 2007] showing that by age 80, 42% of the Spanish population is currently disabled. Looking at population pyramids and expected population growth, we could expect that by the year 2100, more than 1 billion people will be disabled worldwide. It is in light of those statistics that service robotics may play a major role in providing life comfort after losing mobility. In this context, the Human Centered Robotics Lab (HCRL) at the University of Texas at Austin is interested in the study of robotic systems for the assistance, augmentation, and representation of people to increase their social comfort, productivity, security and health.

FIGURE 1 Depiction of NASA's Valkyrie humanoid robot working alongside humans in firefighting activities.

HUMANOID ROBOTS FOR FIREFIGHTING

The US Office of Naval Research has a comprehensive program in Cognitive Science and Human Robot Interaction. One of its main missions is to develop a robotic workforce that supports firefighting operations in Navy vessels. In 2012, the US Navy lost a Los Angeles class nuclear submarine due to an arson fire. Seven firefighters suffered from injuries. The vessel was irreparable and ultimately decommissioned in 2013. Events like this and other emergency scenarios greatly motivate the use of robotic systems that can skillfully move in cluttered spaces. The Human Centered Robotics Lab works with the US Office of Naval Research to study legged mobility and physical human robot interaction. Bipedal locomotion dates back to the 1970s in the former Yugoslavia [Vukobratovic, 2005] with the introduction of center of pressure models to describe human gait. It was followed by work on humanoid robots by Japanese researchers in the early 1970s [Kato, 1973], Honda Co. [Hirose, 2001] and the Japanese Ministry of Science and Technology [Kajita, 2002] based on a simple locomotion model called the Linear Inverted Pendulum Model. MIT pioneered agile bipedal locomotion using Rule Based Methods that enabled robots to run, jump and perform flips in the air [Raibert, 1984].

Sampling based methods have been successful for slow climbing [Bretl, 2005] and quasi-static mobility in rough terrains [Hauser, 2008] but not fast enough for fall recovery. Point feet robots have been recently able to balance unsupported [Ramezani, 2015, Buss, 2014]. Despite those advancements, we lack a general feedback control and planning framework that is not specialized to one type of agility. We also lack realtime plug and play control middleware for legged robots. In 2012 we started building a teen size bipedal robot, Hume (see **Figure 2**) equipped with series elastic actuators for fundamental studies on agility. Series elastic actuators are a technology developed by [Pratt, 1995] which adds a spring in series with an actuator's mechanical output. Its advantages or disadvantages over more rigid actuators are greatly disputed but there is a consensus that they better protect legged robots against shocks and that they provide better force control at low frequencies than rigid actuators equipped with load cells. Point foot bipeds are very interesting because they are relatively simple to build and excellent for testing dynamic balance.

FIGURE 2 The Hume biped robot designed by the Human Centered Robotics Lab and Meka Inc. for mobility in cluttered environments.

FIGURE 3 The UT-SEA Actuator Concept implemented in NASA's Valkyrie lower leg.

To accomplish biped locomotion, a strong focus needs to be put forth at three levels: motion planning for foot placement, body pose estimation, and feedback control of the stance and swinging legs. This process is much different than in mobile manipulation systems, in that bipeds are underactuated systems that will fall very quickly if their feet don't regulate the walk. Equally importantly, body pose estimation is difficult because it needs to rely on inertial data, which suffers from drift when resolving the robot's global pose. When the above three technologies are achieved, for instance using a multi-body physics based simulation environment [Haan, 2009], there is still a long haul until the real robot can balance. This issue is a big hurdle because it leads to naive assumptions that ultimately achieve poor performance in the hardware. The cause of the divide between simulations and hardware is rooted in several key issues: (1) the increased use of expensive control algorithms which introduce realtime delays on the feedback servo processes; (2) the lack of passivity properties of force controlled actuators; (3) the design of slow serial communication processes which introduce additional servo latencies; and (4) the use of inaccurate models for kinematics and dynamics. We will discuss the first two issues below.

HIGH DIMENSIONAL CONTROL ALGORITHMS

Whole-body control algorithms [Sentis, 2007] consider the floating base rigid body dynamics of robots with physical constraints [Jain, 1991]. The control problem is posed as that of creating multiple control objectives while contacts and dependent degrees of freedom are modeled as constraints in an optimization problem. This problem can be solved using projection-based techniques like Operational Space methods [Khatib, 1986a] or Jacobian-transpose methods [Pratt, 2001]. The main advantage of projection operators is that they don't require time-consuming optimization. The second option is the use of optimal control methods [Stephens 2010, Todorov 2012], which allow for inequality constraints but at the cost of slower computa-

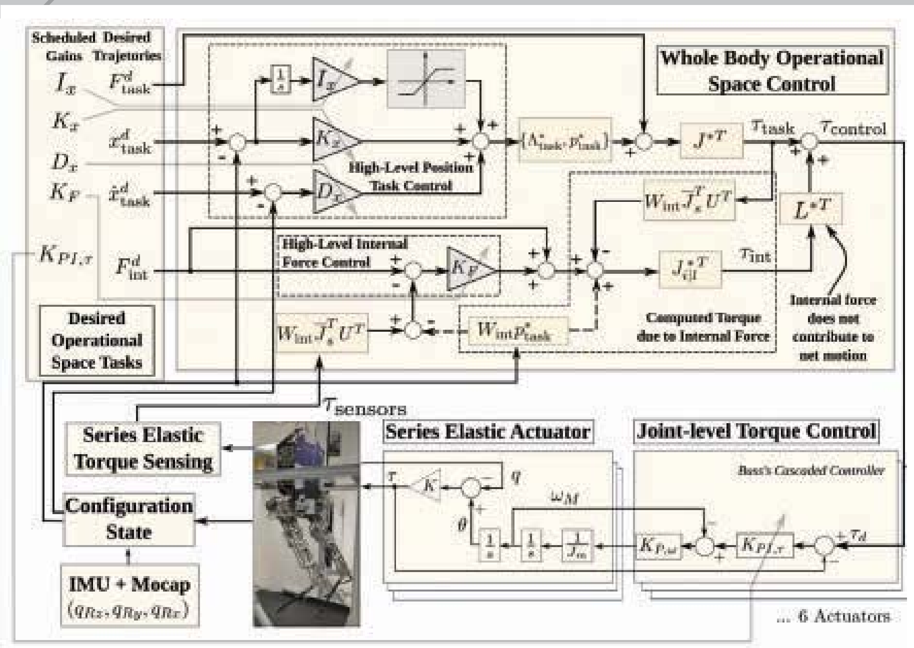

FIGURE 4 Schematic of the Whole-Body Operational Space Controller implemented in the Hume bipedal robot.

rotor supported by an inner piston drive. The back of the ballscrew is connected to a sliding carriage, which contains preloaded springs connected to a floating cage. While the ballscrew is connected to the output joint, the back of the floating cage is anchored to the leg. The spring provides impact protection and excellent torque sensing for feedback torque control.

In our recent paper [Zhao, 2014b] we investigated the effects of time delays in force controlled actuators. We observed that the closed loop position control bandwidth of proportional-derivative controllers is very sensitive to velocity loop delays but fairly insensitive to position loop delays. In order to increase the position control effort for good tracking accuracy, high velocity gains are required to achieve adequate damping. This is particularly important in series elastic actuators because the inner torque controller virtually eliminates the passive friction of the actuator. However, due to the high sensitivity to delays of velocity feedback servos, it is difficult to achieve high position bandwidth on series elastic actuators if the velocity feedback is slow. Using the distributed control architecture previously discussed solves this problem by offloading the velocity servos to low latency embedded processors.

tions. Either way, whole-body control algorithms introduce significant latencies compared to computations of high performance industrial robot controllers. At the same time velocity servo loops are very sensitive to delays [Zhao, 2014a] and therefore stability gets hindered. To mitigate this performance problem we recently proposed using distributed control architectures in which position servos are centralized to allow the use of global robot information and sensor processes while velocity servos are embedded for high speed. Additionally, we recently implemented multi-threaded controllers for speed increase [Fok, 2015].

HIGH IMPEDANCE CONTROL OF SERIES ELASTIC ACTUATORS

In point foot locomotion, the precise tracking of desired swing foot trajectories is essential. Errors above 2cm on foot landing lead to dramatic changes on the locomotion patterns, which quickly become impossible to stabilize. In humanoid robots, this level of precision is hard to achieve compared to industrial robots. First, humanoid robots are increasingly lighter, utilizing flexible mechanical structures, like carbon fiber tubes [Slovich, 2012]. Second, the increasing use of force control actuators for safety introduces stability problems due to the virtual elimination of passive friction.

Third, the computational and communication latencies mentioned before mean that there is degradation on controller stability. In **Figure 3**, we show a type of series elastic actuator used in NASA Valkyrie's robot [Radford, 2015] that the HCRL originally invented [Paine, 2014]. It consists of a hollow electric motor, which turns a ball nut connected to the rotor. A ballscrew slides in and out of the

WHOLE-BODY OPERATIONAL SPACE CONTROL FOR LOCOMOTION

Operational Space Control is a control strategy created a few decades ago [Khatib, 1986b] for industrial manipulators that enables the achievement of unified motion and force control of the robot's end effector. It does not require having a multi-axis load cell in the end effector, and instead relies on estimating the end effector forces using joint torque sensors or joint currents. More importantly, because it is model-based it requires less control effort to achieve the desired motions and forces. A current trend in human-centered robotics is to rely more on feedforward control and less in feedback effort to achieve higher system efficiency and some level of safety upon collisions with the environment.

A few years ago, we extended Operational Space Control to humanoid robots. Humanoid robots can be modeled as multibody systems with a floating base and in contact with the ground or other surfaces. We branded our strategy for unified control of motion and forces, Whole-Body Control, and it has nowadays influenced various related frameworks [Righetti 2012, Johnson, 2015, Stephens, 2010, Ott, 2014].

Most recently, colleagues and I co-founded the IEEE Technical Committee on Whole-Body Control, gathering about 100 researchers working on humanoid robotics. The algorithm that my group at the University of Texas at Austin has developed is called Whole-Body Operational Space Control (WBOSC) and at its core, it uses floating base inverse dynamics as the robot model. Borrowing from the Operational Space formalism, Whole-Body Operational Space Control solves the floating base inverse dynamics problem with contact constraints and derives the so-called Contact-Consistent Task Jacobians which project operational space forces into actuator torques while complying with the contacts on the robot's body.

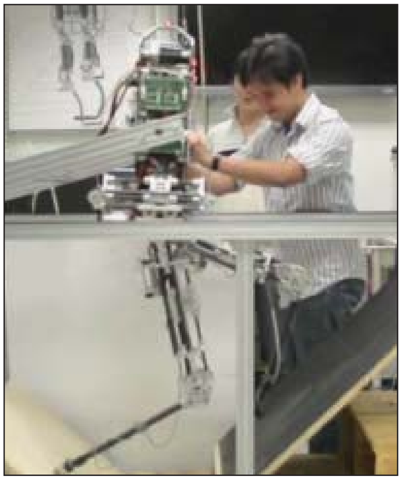

FIGURE 5. Multicontact control of the Hume biped standing on a V-shaped terrain while being disturbed by a student.

In **Figure 4** we show the Whole-Body Operational Space controller implemented in the Hume bipedal robot to perform dynamic locomotion and complex multicontact maneuvers. This type of implementation is the first to use internal force feedback control to balance in cluttered terrains like the one shown in **Figure 5**. This is achieved thanks to the feedback control of the internal forces to overcome the vertical forces exerted by gravity and the person pushing the robot down. Gain scheduling is another important capability of our whole-body controller. As the robot's legs make or break contact, the robot dynamics rapidly change. Although the models used in Whole-Body Operational Space Control attempt to compensate for these changes, the controllers need to be further specialized for each locomotion phase, and this is accomplished by scheduling the gains.

THE DARPA ROBOTICS CHALLENGE

In 2012, we teamed up with NASA Johnson Space Center to build a new humanoid robot to compete in DARPA's Robotics Challenge (DRC). The challenge emerged after the Fukujima Daiichi Nuclear Disaster of 2011 that could have been avoided if unmanned systems could have been deployed to deliver fuel or energy batteries to run the cooling systems.

For the challenge we performed a herculean effort to help build an entire humanoid robot from scratch, a whole-body control software to coordinate mobility and manipulation, and a supervisory system to program the robot's behaviors from afar.

ControlIt!

During the DRC we developed software that implemented the Whole-Body Operational Space Control methodology on Valkyrie and dubbed it ControlIt! ControlIt! is multi-threaded to significantly increase achievable servo frequencies using standard PC hardware. It builds upon state-of-the-art software such as Eigen 3.0.5, RBDL 2.3.2, and Robot Operating System (ROS) Hydro and Indigo, and the Gazebo simulator 4.1.0. A parameter binding mechanism enables tight integration between ControlIt! and external processes via an extensible set of transport protocols. A plugin-based architecture enables ControlIt!'s core software to be platform independent and the set of whole body control primitives to be runtime extensible. To support new robots, only two plugins and a URDF model need to be provided — the rest of ControlIt! remains unchanged. New whole body control primitives can be added at runtime by writing a Task or Constraint plugin. ControlIt! comes with plugin libraries containing existing task primitives, robot integration components, and a parameter binding transport layer that provide sufficient functionality for basic applications.

CONCLUSIONS

Whole-Body Operational Space control emerges as a capable framework for realtime unified control of motion and force of humanoid robots. By exploiting the rigid body dynamics of systems, it could theoretically outperform

FIGURE 6 The making of NASA's Valkyrie with the involvement of the HRCL. On the right, Valkyrie competes in the DRC Trial sessions in Miami in December 2013.

high-speed industrial manipulators while providing the grounds for new types of service-oriented applications that require contact. By relying on joint torque sensors, WBOSC opens up the potential to interact with the physical environment using any part of the robot's body while regulating the effective mechanical impedances to safe values. This capability is very important in human-centered applications because the robot could not only detect collisions on any mechanical linkage of its body but also respond to collisions with low impedance behaviors to provide safety.

Until recently no whole-body control software environment with a focus on usability and integration with modern math and communication libraries had been developed. With ControlIt! we provide a strict and easy way to use the WBOSC API consisting of compound tasks which define the operational space, and constraint sets which define the contacts with the environment as well as dependent degrees of freedom. ControlIt! is well integrated with the latest Ubuntu operating system, the RTAI realtime Kernel, the Robot Operating System, visualization tools, and several libraries for algebraic and rigid body dynamic computations. Additionally, to shave time on computation, ControlIt! relies on a multi-threaded architecture in which the feedback servos, the global models and the task models are computed as separate processes. This implementation allows achieving rates that significantly reduce the tracking error for practical operations. ControlIt! is easy to connect to high level planners. During our participation in DARPA's Robotics Challenge, the behaviors of ControlIt! were programmed using NASA's Robot Task Commander software [Hart, 2013]. More recently, new behaviors have been programmed using Smach from the ROS framework. In the near future, we will support visual servoing to achieve adaptive manipulation of everyday objects in the environment. Also, we will pursue cloud based capabilities and an advanced user interface for programming and calibrating behaviors. ■

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FROM TORQUE-CONTROLLED TO INTRINSICALLY COMPLIANT HUMANOID ROBOTS

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For fulfilling predefined tasks of rather low complexity, specialized automats usually do a better job than general purpose machines, such as humanoid robots. Yet, for more complex and diverse tasks in a priori unknown human environments general purpose humanoids can provide a high degree of flexibility. In certain scenarios such as disaster management, robots may have to use tools and navigate through environments that were designed for humans. This is obviously true also if we think about future general purpose household robots, able to carry out all human housekeeping tasks. This motivates the design of anthropomorphic robots such as TORO and Rollin' Justin. Also in tele-operation scenarios, human-like robots tend to be more intuitively operated by humans, due to their kinematic similarity.

Torque-controlled humanoid robot Rollin' Justin.

There is one further strong reason why researchers build humanoid robots: understanding and technically reproducing such seemingly simple human tasks like dexterous grasping and manipulation, balancing, walking and running, perceiving the surrounding environment for planning and executing daily tasks are still largely unsolved questions, at least when compared to the human performance. Thus humanoid robot research helps to answer fascinating questions about human capabilities on the one hand, provides clues to build more dexterous, efficient and general purpose machines on the other hand.

In this paper we give an overview of the advancements in humanoid robotics at the German Aerospace Center (DLR) over the last decade.

The development started with focus on dexterous, bimanual manipulation with the wheel-based humanoid Rollin' Justin and continued with legged locomotion on TORO. Both robots are characterized by torque-controlled actuators, capable of emulating the adaptable human muscle compliance by feedback control. A new generation of actuators is developed for the humanoid upper body HASY (Hand Arm System), in which "muscle compliance" is realized mechanically, by variable compliance actuators. This step promises increased impact robustness and energy efficiency by elastic energy storage, but raises at the same time substantial additional challenges regarding mechatronic integration and control.

TORQUE-CONTROLLED HUMANOIDS

The DLR Light-Weight-Robot-III [1] represents the third generation of torque-controlled robot arms developed at DLR. One of the main features of this robot is a tight mechatronic integration of strain-gauge-based torque sensors at the power-output side of the drive units. Such torque sensors allow for effective vibration damping in highly dynamic operations. Moreover, low-level torque feedback loops produce a highly sensitive back-drivable closed-loop behavior despite the highly geared drive units required by the lightweight construction of the joints. As a result, model-based nonlinear control approaches, such as impedance control, can be implemented successfully based on this technology. These drive units build a mature technological basis for the complex humanoid robots Rollin' Justin and TORO **(Figure 1).**

Autonomous Compliant Manipulation with Rollin' Justin

The mobile humanoid robot Rollin' Justin is utilized as a research platform for autonomous planning and control of manipulation tasks in human

FIGURE 1 **Robots described in this article: Torque-controlled humanoid robots TORO and Rollin' Justin, and the elastic Hand Arm System.**

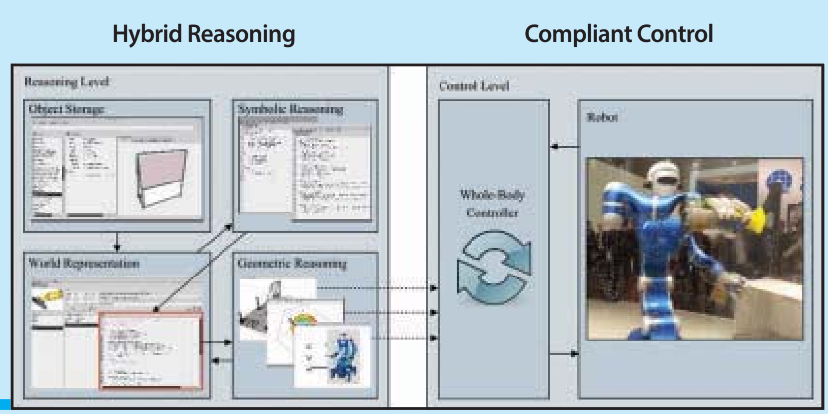

FIGURE 2 **Rollin' Justin combines a multi-task whole-body impedance controller with a high level reasoning unit acting both on symbolic, object and task level, and on the geometric level of the motion planner.**

environments. The system consists of an omnidirectional platform, an articulated torso, two seven degrees-of-freedom arms, two four-fingered dexterous hands, and a multi-sensory head (see **Table 1** & **Table 2**). The hands are equipped with position and torque sensors and can thus be used for complex manipulation tasks: for example for handling tools or unscrewing the lid of a container or bottle. Rollin' Justin can be operated without wires for about one hour. The size and geometry of the footprint of the mobile base can be adapted to the task by coordinating the movements of the four steerable spring-borne wheels. Overall, the robot can reach objects up to a height of 2.7m while still fitting through standard doorways. The vision system consisting of RGB-D cameras mounted in the head and the platform and a stereo camera pair allows for the 3D reconstruction of the environment.

With Rollin' Justin we aim to create a cognitive robotic system that is able to reason about compliant manipulation tasks, based on intelligent decisions according to the actual state of the environment. In order to cope with a wide variety of tasks, we utilize a knowledge-based hybrid reasoning system to plan the task execution autonomously on the symbolic level (i.e. which actions have to be scheduled to satisfy the commanded goal state) and on the geometric level (i.e. what are appropriate task parameters to manipulate the objects involved in the actions) [2]. Moreover, during the reasoning procedure, the robot parametrizes the control level for each task execution individually. A hierarchical whole-body impedance control framework [3] builds the behavioral basis for the higher-level reasoning system **(Figure 2)**. For each task, the robot selects and parameterizes the required control strategies (e.g. Cartesian impedance control, singularity avoidance, and self-collision avoidance) and the controller parameters (i.e. Cartesian trajectory, Cartesian stiffness, and maximum allowed Cartesian forces) based on the requirements of the objects involved in the task execution and the environment.

Exemplary tasks in domestic environments involve wiping of windows, cleaning the dishes and collecting dust or shards with a broom, as demonstrated in the video [4]. These tasks share the need for coordinated whole-body motions, while a tool is guided along a surface in contact. The tasks can be executed with the same overall control strategy, only requiring a different parameterization.

Attribute	TORO	Rollin' Justin	Hand/Arm System
Weight	76 kg	about 200 kg	35 kg
Load capacity	10 kg	20 kg	15 kg
Battery time	1 h *(during operation)*	1 h *(during operation)*	n.a.
Height	1.74 m	1.91 m	1.8 m *(including stand)*
Locomotion velocity	up to 0.5 m/s	up to 2 m/s	—
Vision system	Head: 1 RGB-D camera & set of stereo cameras	Head: 1 RGB-D camera & set of stereo cameras Mobile platform: 3 RGB-D cameras	Head: 1 RGB-D camera
Additional sensors	1 IMU in the head 1 IMU in trunk 1 FTS in each foot	1 IMU in the head 1 IMU in mobile platform	—

TABLE 1 Overview of the main characteristics of the humanoid systems described in this article.

Subsystem	TORO	Rollin' Justin	Hand Arm System
Arms	2 x 6	2 x 7	2 x (7+7)
Hands	2 x 6	2 x 12	2 x (18+18)
Torso	1	3	—
Neck/Head	2	2	(4 under development)
Locomotion System	2 x 6 (legs for walking)	8 (for free planar motion)	—
Sum	39	51	104

TABLE 2 Degrees of freedom of the three humanoid systems described in this article.

Balancing and Walking with TORO

While Rollin' Justin's main focus is on safe human-robot interaction, complex whole-body motions, bimanual manipulation and other high-level tasks, the bipedal humanoid TORO was built with the aim of evaluating similar torque-based control concepts also for a legged robot. The relevant tasks for TORO include bipedal walking and multi-contact balancing, i.e. compliant stabilization against external disturbances while sustaining two or more end-effectors in contact. In contrast to the dexterous torque-controlled hands of Rollin' Justin, the hands of TORO are human hand prostheses (iLimb ultra) allowing for a robust grip in multi-contact operations but without sensor feedback. Six-axis force-torque sensors in the feet allow

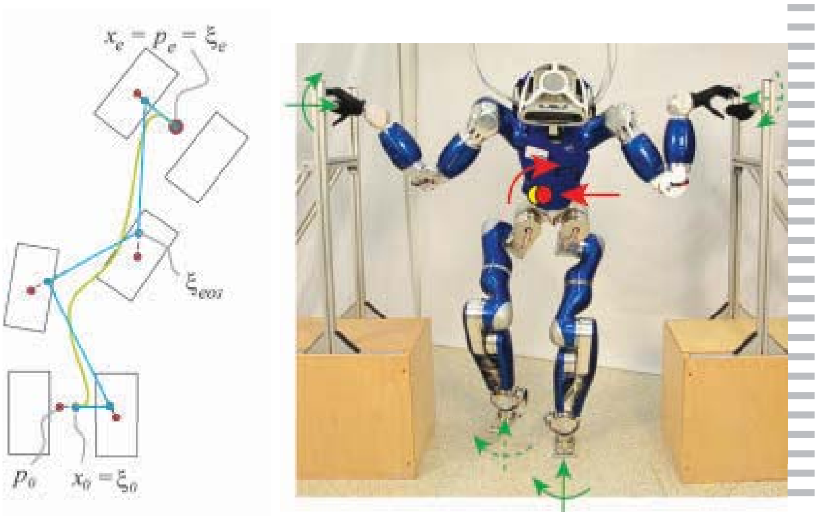

FIGURE 3 **Illustration of the control approaches used for the bipedal humanoid TORO. Planning of constant reference ZMP locations in the feet imply a linear evolution of the reference Capture Point during walking. In situations involving multiple contact points, desired control forces on the CoM are distributed amongst the available contacts.**

measurement of the Zero-Moment-Point (ZMP), i.e. the torque-free point of action of the gross contact force, an inertia measurement unit (IMU) in the trunk is used for real-time control. In accordance with the aim of studying dynamic walking approaches, the feet were designed relatively small, having a size of 19 x 9,5cm. The multi-sensory head consists of a stereo camera, a RGB-D sensor and an additional IMU, which are fused by an onboard computer to provide an ego-motion estimation (based on an extended Kalman filter) and a mapping of the environment. The onboard batteries in the backpack allow for an autonomous operation of up to 1h.

Our approach for the generation and stabilization of walking motions is based on the concept of Capture Point, which is defined as the point on the floor where the robot has to place the ZMP in order to stop within one step. It can be shown that the use of the Capture Point as a state variable separates the overall dynamics into the stable and unstable part. For gait stabilization we utilize an underlying position-based ZMP controller and treat the ZMP as the control input. Moreover, from the Capture Point dynamics one can also see that a sequence of constant ZMP locations (associated with the footsteps) leads to a Capture Point trajectory, which geometrically is simply a connection of lines (zig-zag-curve, **Figure 3**). As a consequence, the trajectory generation can be performed in a highly efficient way as part of the real-time controller [5].

Motivated by the successful implementation of torque-based impedance controllers for manipulation with Rollin' Justin, we developed a balancing controller for TORO which builds up on the torque-controlled operation mode of the joint drive units. The controller aims at generating a desired wrench (6-dimensional force-torque vector) at the CoM of the robot [6]. This desired wrench contains a compensation of the robot's total gravity force and a proportional and derivative control action responding to deviations of the CoM and hip orientation from a desired equilibrium configuration. Then a set of contact forces for the end-effectors in contact is computed by an optimization formulation considering unilaterality and friction cone constraints. Finally, the contact forces for all end-effectors are realized by mapping the forces into desired joint torques, which are transferred as set-points to the underlying joint torque controllers. The algorithm has been evaluated in a series of balancing experiments with two (only feet) to four (feet and hands) end-effectors in contact (see Figure 3), including balancing on movable inclined planes, rocks, and even on compliant surfaces (sports mattresses). Current extensions of this controller focus on the realization of dynamic changes in the number of contacts as well as on combinations with the Capture-Point-based algorithm for gait stabilization.

THE HAND ARM SYSTEM

What does it aim at?

The Hand Arm System is a DLR development towards the next generation of humanoid robots in terms of mechatronic design. The aim is to reach the performance of human beings in terms of speed, force and accuracy [7]. Its design philosophy is to understand the biological system and implement the technology to provide a functional equivalent but avoid making a blind copy of the biology.

How does it work?

In humans, the elasticity provided by the

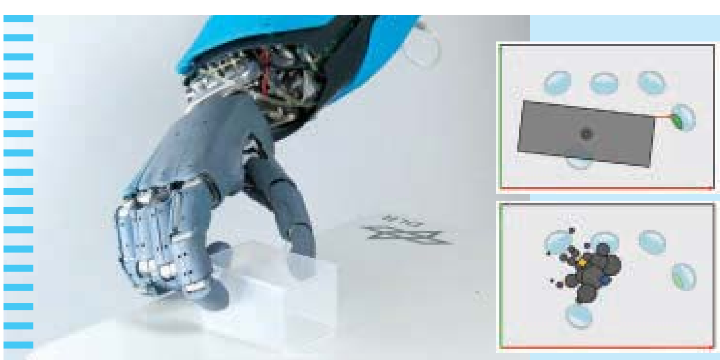

FIGURE 4 **Execution of a plan obtained by grasp and arm planning. In-hand object localization is obtained by fusion of kinematic, tactile and vision data. A particle filter uses a simplified object model and the robot kinematics and tactile sensing capabilities in order to discard or promote object location hypothesis. On the left, a typical pick-and-place task is executed. On the right top, the picture depicts an invalid hypothesis (collision and unexplained contact). On the right bottom, the diagram depicts how the particles reflect the hypothesis quality (the larger the circle, the better the hypotheses). The approach allows monitoring the grasp execution interactively and significantly improves the success rates.**

muscles, tendons and ligaments decouples the link position from the drive position. Generally speaking, the energy introduced into the system, no matter whether caused by a collision, external forces or acceleration of the link inertia, is converted to elastic energy. This power source can be used to regain kinetic energy and therefore enhances the dynamics of the system. This motivated the introduction of mechanical springs, placed between the output of the gear box and the link to provide a similar behavior. Moreover, by using several nonlinear mechanisms actuated by two motors per joint, it is possible to adjust the stiffness of the joints and adapt to the task requirements.

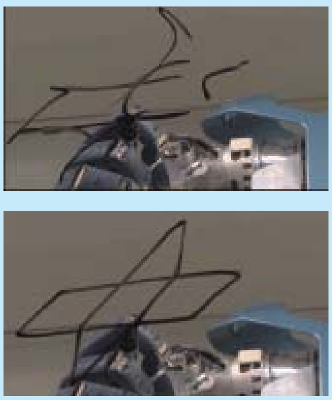

FIGURE 5 Improvement of trajectory tracking by active vibration damping (bottom).

System Overview

The Hand Arm System is an upper body humanoid robot with two arms and hands. All of its 48 joints are actuated with nonlinear, adjustable stiffness mechanisms. It is equipped with more than 300 sensors and 100 motors that are controlled at a frequency of 3kHz. We experimented with different concepts of implementing variable intrinsic compliance [8].

Current Work

The platform is used to investigate and experiment modeling and control but also on new planning and grasping strategies **(Figure 4)**.

A typical application demonstrating the potential of compliant actuators is illustrated in Figure 1 (bottom). The arm is driven in mechanical resonance to achieve link velocities above the motor velocity and allow impact torques which are above the maximum motor and gearbox torques. The impact force peak is absorbed and smoothened by the spring. Despite the large actuator compliance, positioning precision is achieved by iterative learning control.

A disadvantage of the very compliant actuation is the low damping of the system when performing fast positioning motions based only on motor position information. However, measuring the joint torque and its derivative based on the spring deflection [9] allows applying nonlinear control techniques to effectively damp out these oscillations **(Figure 5)**.

CONCLUSIONS AND OUTLOOK

Our overall goal is to develop safe and robust humanoid robots that are capable of performing a multitude of complex tasks and hereby contributing to human welfare. While a decade ago, humanoids seemed far too complex for realistic scenarios, the current results encourage us to imagine first applications within the next decade. Possible fields of use include service robotics, industrial coworkers, search and rescue, space applications and medical robotics, to name but a few. Teleoperated scenarios are feasible in short term, developing in long term towards shared or even full autonomy. Still, advancements have to be made in almost all areas, starting from mechatronic robustness, reliability and energy efficiency, over multimodal perception and control up to autonomous planning and AI-based reasoning. Development of interaction interfaces and communication modalities to humans will play an increasingly important role in the future. ■

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COMPLIANT LOCOMOTION:

As bipeds, humanoid robots have the potential to far surpass the performance of wheeled platforms in tasks requiring a high degree of mobility in natural and man-made environments. In nature, bipeds such as humans and birds are highly adept at traversing difficult and diverse terrain with both speed and agility. In order for humanoids to reach their full utility, comparable control strategies will need to be developed for legged robots. Legged animals often employ highly dynamic gaits to achieve fast and efficient locomotion, despite limited range of motion and muscle strength. To do so, animals utilize active and passively compliant control strategies to maintain balance in response to external disturbances and unpredictable terrain [1].

It is no surprise that compliant control strategies offer a number of advantages for humanoid locomotion. Low joint stiffness can help minimize damage to mechanisms and actuators in the event of a collision and improve the safety of robots operating in close proximity to humans. In the robotics literature, compliant control is often achieved using force controllable actuators. The ability to closely regulate internal and external forces during

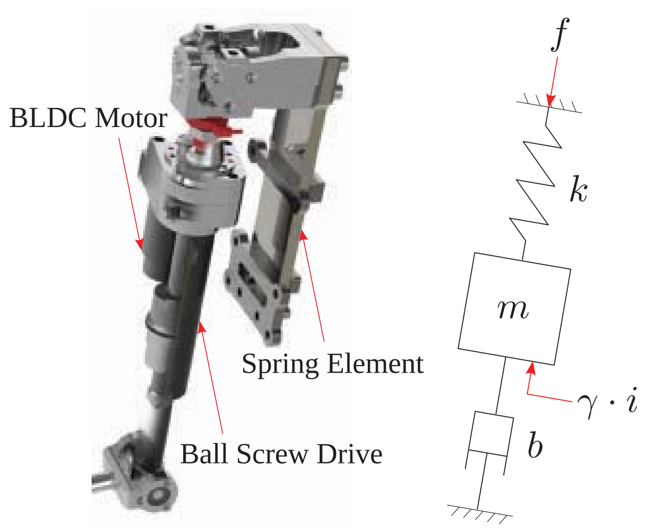

FIGURE 1 Left: THOR linear series elastic actuator. Right: Lumped spring-mass-damper model of a series elastic actuator with fixed output load.

locomotion enables naturally compliant behaviors capable of adapting to uncertain terrain features encountered in real-world environments. Regardless of the chosen actuation strategy, the design of humanoid locomotion controllers is greatly complicated by the underactuated and nonlinear nature of the associated multibody dynamics. Additional difficulties arise due to the significant unmodeled dynamics present in real mechanical systems.

High feedback gains can help to mitigate the effects of unmodeled dynamics during locomotion at the expense of "stiff" and often unpredictable interactions with the environment. On the other hand, compliant locomotion strategies permit excellent control of interaction forces, yet require accurate feedforward planning and control to achieve comparable tracking performance. As such, one of the major challenges in developing compliant locomotion strategies is selecting appropriate dynamic models. Simple models are commonly employed to aid in the design of robust, real-time control laws, while complex models offer increased dynamic accuracy for torque-controlled humanoids. Given a suitable model, the remaining challenge lies

A MODEL-BASED APPROACH

by Michael Hopkins, Robert Griffin and Alexander Leonessa
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in developing high-performance, low-stiffness controllers that can adapt to a wide variety of challenging and unpredictable environments.

COMPLIANT ACTUATION

Drawing inspiration from biology, researchers have begun to incorporate passive mechanical compliance into the design of legged robots, often by adding spring elements in series with the robot's actuators. First introduced by the MIT Leg Laboratory, series elastic actuators (SEAs) have been shown to improve the fidelity and stability of closed-loop force controllers while simultaneously increasing shock tolerance [2]. **Figure 1** shows an example SEA utilized in the design of THOR, a compliant humanoid robot developed at Virginia Tech. Linear forces are generated by a brushless DC motor that drives a two-stage transmission composed of a belt drive and precision ball screw. The actuator's spring element consists of a compliant titanium beam subjected to moment loading.

Series Elastic Actuator Model

SEAs are often modeled as simple spring-mass-damper systems assuming a fixed output load. The open-loop transfer function is given by

$$\frac{F}{I} = \frac{\gamma \cdot k}{m \cdot s^2 + b \cdot s + k} \quad (1)$$

where F is the output force, I is the commanded motor current, γ is the D.C. gain, k is the spring stiffness, b is the transmission damping, and m is the equivalent lumped mass of the motor, transmission, and reflected rotor inertia [3]. The spring stiffness selection is a key design variable for SEAs. When tracking a zero force reference, the spring deflects immediately under load, allowing the motor additional time to regulate the output force by accelerating the transmission. As such, a design tradeoff exists due to the favorable low mechanical impedance of a soft spring and high control bandwidth of a stiff spring.

Tracking Force and Torque Trajectories

Force and torque control strategies for linear and rotary SEAs typically rely on some variation of feedforward and feedback control to accelerate the rotor in response to the estimated spring deflection [2; 4]. The THOR SEA force controller combines feedforward and PID control with a model-based disturbance observer (DOB) based on measurements from an inline load cell sensor. The DOB estimates unmodeled disturbances such as nonlinear friction forces and attempts to cancel their effect through feedforward control. Given the measured output force, the disturbance signal is estimated by comparing the commanded motor current with the estimated motor current obtained from an inverse model of the open-loop actuator plant in Eq. (1). The combined approach offers excellent force tracking with a closed-loop bandwidth of 30 Hz at 200 N (approximately 10% of the peak actuator force), despite observing roughly 200 N of stiction in the actuator transmission.

The THOR humanoid features a rigid skeletal structure with rotary joints similar to the human musculoskeletal system. Shown in **Figure 3**, the robot's linear SEAs are arranged in serial and parallel configurations spanning the hip, knee, and ankle joints. For the purposes of high-level control, it is often convenient to command the torques and accelerations about each joint, as opposed to the individual forces imparted by each actuator. A simple solution is to track equivalent actuator forces obtained from an inverse statics solution for each joint mechanism. **Figure 2** shows the desired and estimated joint torque trajectories for the hip pitch joint using the aforementioned approach. For this experiment, the torque reference trajectory was selected to emulate the motion of the swing leg during walking. The

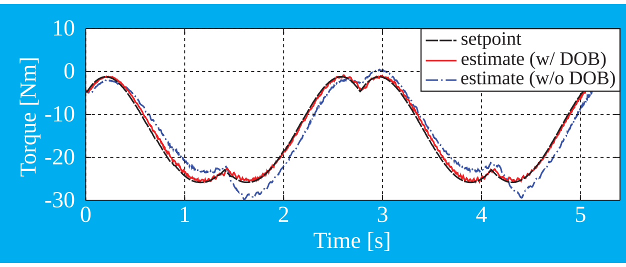

FIGURE 2 Hip pitch torque tracking with and without actuator disturbance observer.

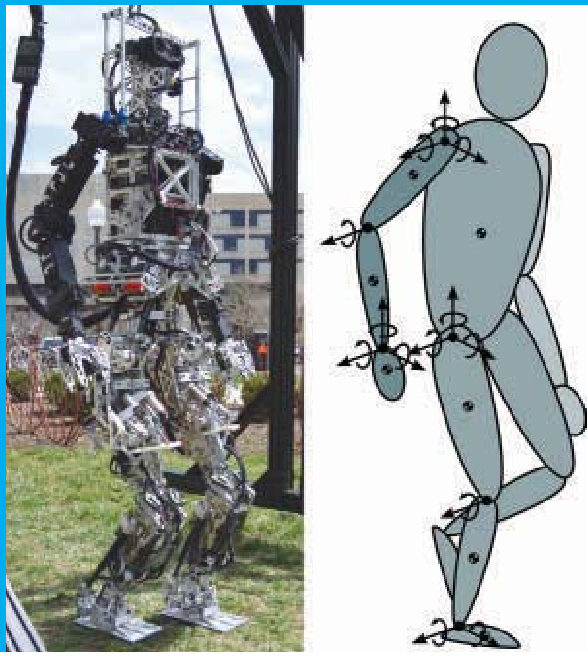

FIGURE 3 Left: THOR, a series elastic humanoid developed at Virginia Tech. Right: Rigid body model of an articulated humanoid.

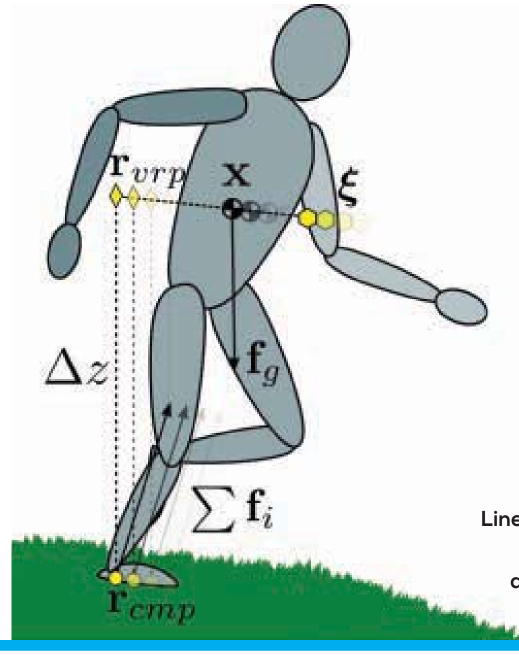

FIGURE 4 Linear centroidal dynamics of an articulated humanoid.

results show that the use of a disturbance observer significantly reduces torque tracking errors due to stiction and model uncertainty.

WHOLE-BODY CONTROL

The underactuated mechanics of legged locomotion have inspired decades of diverse research into control techniques for humanoid robots. These techniques often rely on position and velocity feedback obtained from proprioception sensors to compute admissible joint setpoints for whole-body control. In order to reduce the complexity of the high-dimensional control problem, whole-body behaviors such as dynamic walking are often decomposed into constituent motion tasks that can be tracked using simpler low-dimensional controllers. Example tasks include positioning the swing foot, rotating the upper body, and accelerating the center of mass. Many torque-based whole-body control strategies employ convex optimization techniques to minimize the aggregate error associated with each motion task [5-8]. In order to compute optimal torque setpoints for each joint, these techniques require an approximate model of the whole-body dynamics.

Rigid Body Humanoid Model

While mechanical compliance can dramatically improve the performance of low-level force and torque control strategies, structural rigidity is often highly valued in the design of legged robots. Assuming the deformation of each link is sufficiently small under load, articulated humanoids are typically modeled as rigid body systems. In order to decouple the actuator dynamics from the high-level controller design, a number of approaches assume that the actuator controller is capable of approximating an ideal torque source at each joint [4-7]. In this case, the rigid-body equations of motion are given by

$$\begin{bmatrix} 0 \\ \tau \end{bmatrix} = H(q)\ddot{q} + C(q,\dot{q}) - \sum_i J_i^T f_i \qquad (2)$$

where $\tau \in R^n$ is the vector of joint torques, $q \in R^{n+6}$ is the vector of generalized coordinates (including the joint positions and 6 DOF floating base frame), $H(q)$ is the joint-space inertia matrix, and $C(q,\dot{q})$ is the vector of centrifugal, Coriolis and gravity torques. The final term accounts for external contact forces acting on the robot, where J_i and f_i represent the point Jacobians and force vectors corresponding to each contact point, i=1...N.

Solving The Inverse Dynamics

Whole-body control of the THOR humanoid is achieved using an inverse dynamics solver that computes admissible joint torques given a set of desired motion tasks including Cartesian accelerations, joint accelerations, and momentum rates of change [7]. Task-space accelerations and forces can, in general, be expressed as a linear combination of the joint velocities and accelerations. This allows the inverse dynamics problem to be formulated as an efficient quadratic program (QP). The QP is designed to minimize a cost function based on the weighted sum of squared errors for each motion task, where the decision variables include the joint accelerations and generalized contact forces. The relative weight of each cost term can be tuned to enforce a soft prioritization of motion tasks. To ensure that the optimized values are achievable by the hardware platform, the optimization includes constraints related to the available control authority, range of motion, and frictional contact points.

Given the optimized accelerations and contact forces, the corresponding joint torque setpoints are computed from the rigid body equations of motion given by Eq. (2). Due to model uncertainty, instability issues sometimes arise when implementing inverse dynamics approaches on torque-controlled hardware platforms. Low-level damping can help improve joint stability at the expense of dynamic accuracy. To enable whole-body control of the THOR humanoid, low-gain velocity feedback is introduced into the actuator force controller using estimates obtained from pre-transmission motor encoders. The actuator velocity setpoints are obtained by integrating the optimized joint accelerations and solving the forward velocity kinematics for each joint mechanism.

COMPLIANT LOCOMOTION

Dynamic stability, accurate foot placement, and low cost of transport are qualities of human walking that are often desired of humanoid locomotion. Unfortunately, the underlying control policies employed by humans and legged animals remain largely unknown. In the humanoid literature, momentum control has become an increasingly popular method to stabilize a robot's centroidal dynamics during locomotion [8]. Force and torque-controlled humanoids are well-suited to this approach, since momentum rates of change are related to the forces and torques acting on the system.

Centroidal Dynamics

The centroidal dynamics of a rigid body humanoid define the reduced equations of motion for the center of mass, $x \in R^3$, and linear momentum, $l \in R^3$. The CoM acceleration and linear momentum rate of change are governed by Newton's second law, $m\ddot{x} = \dot{l} = \Sigma f_i + f_g$, where Σf_i is the total contact force and f_g is the force of gravity. For dynamic planning and control purposes, it is often convenient to reason in terms of geometric reference points as opposed to the contact forces acting on the system.

The Virtual Repellent Point (VRP) and enhanced Centroidal Moment Pivot (eCMP) define the direction and magnitude of the linear momentum rate of change and total contact force in terms of the CoM position [9]. These closely related reference points can be expressed as

$$\dot{l} = \omega_0^2 (x - r_{vrp}) \qquad \Sigma f_i = \omega_0^2 (x - r_{cmp}) \tag{3}$$

where $r_{vrp} \in R^3$ is the VRP position, $r_{cmp} \in R^3$ is the eCMP position, and

$$\omega_0 = \sqrt{\frac{g}{\Delta z_{com}}}$$

is the natural frequency of the second order CoM dynamics assuming a gravitational constant, g, and CoM height, Δz. As illustrated in **Figure 4**, the VRP lies directly above the eCMP at the nominal CoM height. The eCMP typically lies in the robot's base of support, i.e. the convex hull formed by the contact points on each support foot. When the robot's center of pressure (CoP) is aligned with the eCMP, the line of action for the total contact force passes through the CoM. As a result, it is generally possible to avoid generating angular momentum about the CoM assuming the eCMP does not leave the base of support.

Momentum control approaches can be further simplified by defining an appropriate linear transformation of the center of mass state. The three-dimensional Divergent Component of Motion (DCM), defined as

$$\xi = x + \frac{1}{\omega_0}\dot{x}$$

divides the CoM dynamics into stable and unstable first-order equations of motion [9],

$$\dot{x} = \omega_0 (\xi - x) \qquad \dot{\xi} = \omega_0 (\xi - r_{vrp}) \tag{4}$$

Intuitively, the DCM represents the point at which the VRP must be placed at any point in time to allow the CoM to come to a complete rest. The DCM diverges from the VRP with a time constant of $1/\omega_0$, while the CoM converges to the DCM at the same rate. As a result, the centroidal dynamics can be indirectly stabilized using a simple VRP-based control law to regulate the DCM position where the commanded VRP is mapped to a corresponding linear momentum rate of change objective using Eq. (3).

Designing a Walking Controller

The THOR walking controller is implemented using a simple state machine that responds to external events such as toe-off and heel-strike. At the beginning of each step, the controller computes dynamically feasible joint-space and task-space trajectories given desired foothold poses and step phase durations from a high-level footstep planner. Several low-dimensional controllers are defined to compute whole-body motion tasks that stabilize the open-loop gait. Spatial accelerations for the pelvis orientation and swing foot pose are computed using Cartesian

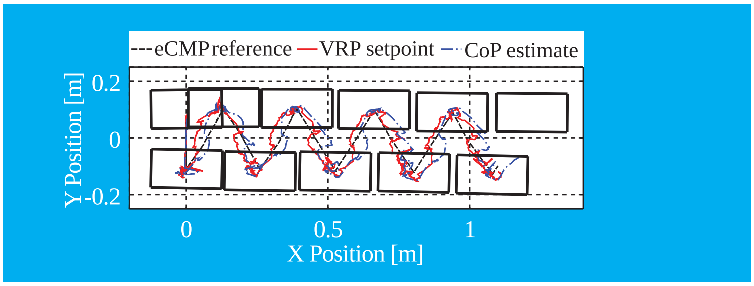

FIGURE 5 Estimated footholds including eCMP reference, VRP setpoint, and COP estimate while walking on flat terrain.

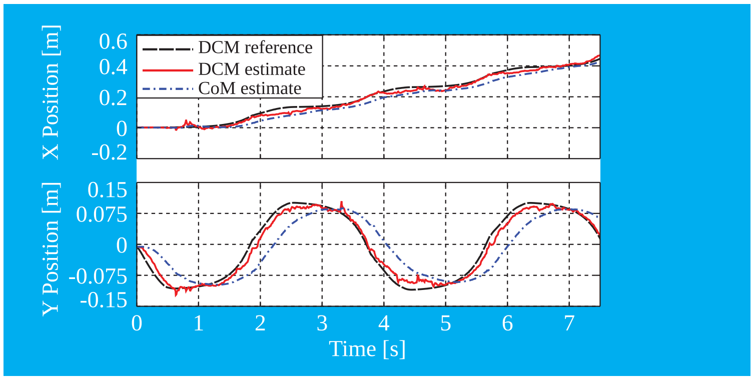

FIGURE 6 DCM and CoM trajectories while walking on flat terrain. The x-axis is aligned to the front of the robot, and the y-axis is aligned to the left.

FIGURE 7 THOR humanoid walking on gravel and grass.

PID controllers to track appropriate 6 DOF trajectories during each step phase, while joint-space accelerations are computed using PD feedback to achieve the desired upper body motion. Angular momentum rate of change objectives are computed using a simple damping controller to regulate the total angular momentum, while linear momentum rate of change objectives are computed using a PI controller to track a dynamically feasible DCM trajectory.

Each controller relies on accurate feedforward trajectories to decrease the minimum feedback gains required to achieve satisfactory tracking performance. When computing the inverse dynamics, relatively high weights are assigned to the linear momentum and swing foot acceleration objectives, while relatively low weights are assigned to the angular momentum and upper body acceleration objectives. This heuristic encourages accurate foot placement, while allowing the upper body DOF to assist the DCM controller for dynamic balance.

EXPERIMENTAL RESULTS

The THOR walking controller has been tested on a variety of terrain types. **Figure 5** shows the estimated footholds and reference point trajectories while walking forward on flat terrain at an average velocity of 0.08 m/s. Note that the eCMP reference passes through the center of the robot's base of support. The VRP setpoint deviates from the reference eCMP trajectory in order to stabilize the DCM trajectory. If the VRP remains within the base of support, the whole-body optimization is generally able to avoid generating significant torque about the CoM by minimizing the distance between the CoP and VRP.

Figure 6 shows the horizontal DCM and CoM trajectories corresponding to the first five steps of Fig. 5. The double support duration is 0.7 s, the single support duration is 1.05 s, and the stride length is 0.14 m. The DCM reference is computed using a combination of reverse-time integration and model predictive control given a nominal eCMP reference trajectory over a 3-step preview window. Accurate inverse dynamics and high-performance torque control enable a high degree of compliance while tracking the DCM, resulting in an inherent robustness to unmodeled terrain features. **Figure 7** shows the robot walking on gravel and grass. Note that the whole-body controller weights and gains used for these outdoor experiments are identical to those used on flat terrain.

NEXT STEPS

Over the past decade, the robotics community has made significant progress in the development of effective compliant locomotion strategies for force-controlled humanoids. As walking and running controllers continue to improve, we hope to gain new insights into the underlying mechanics of human locomotion. Despite new advancements, a number of challenges remain before humanoids can be fielded in real-world applications that require a high degree of mobility. Model-based control approaches could greatly benefit from techniques found in the robust and adaptive control literature. The field is also interested in moving towards more efficient, human-like locomotion using biologically-inspired control strategies. ■

ACKNOWLEDGEMENTS

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HUMAN SUPERVISED CONTROL OF A HUMANOID ROBOT FOR NON-CONVENTIONAL EMERGENCY RESPONSE

The devastation and dangerous operational environments caused by natural and man-made disasters have been the motivation for the DARPA Robotics Challenge (DRC). What if we had been able to prevent hydrogen explosions in the Fukushima Daiichi Nuclear Power Plant by using robots within the first hour after it was hit by a tsunami triggered by the Great East Japan earthquake in 2011? For the past three years, the DRC has mobilized hundreds of robotics researchers, practitioners and makers to accelerate the research and development in robotics for disaster response. The DRC Finals on June 5-6, 2015 bring 25 qualified teams to Pomona, CA to demonstrate their systems in a disaster mission scenario. In a simulated environment, robots perform a variety of manipulation and mobility tasks. The robots operate under human supervision with a 1-hour mission completion time. Communication between the operator(s) and robot is degraded during the mission to promote robot autonomy.

Humanoid robots have advantages for completing a wide variety of tasks in human environments such as opening doors, turning valves, operating power tools, traversing rough terrain and driving a vehicle. However, despite

FIGURE 1 **The Atlas Humanoid Robot provided as a standard platform for the DRC software teams.**
PHOTO: DARPA

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FIGURE 2 Atlas humanoid robot during stair climbing at the DRC Testbed Event in South Carolina.

receiving great attention to date, humanoid robot motion planning and control remain challenging research topics. Completion of the DRC mission with a humanoid robot requires the development of reliable and accurate techniques for perception, full-body motion planning and control, and dexterous manipulation as well as operator training.

The Worcester Polytechnic Institute (WPI)-Carnegie Mellon University (CMU) DRC team, originally known as WPI Robotics Engineering C Squad (WRECS) which took 2nd place in the Virtual Robotics Challenge in June 2013, participated in the DRC Trials as the only Track C team in December 2013. Team WPI-CMU scored 11 out of a possible 32 points, ranked 7th (out of 16) at the DRC Trials, and was selected as a finalist for the DRC Finals. Our team is preparing to participate in the DRC Finals at the time of writing this article. More than the points earned, developing new human-supervised control techniques for the Atlas humanoid robot to complete disaster response tasks has been the focus of our work in the past three years. In this article, we present our approaches, results and lessons learned. We will start by describing the robot hardware for the sake of completeness.

ATLAS UNPLUGGED

In July 2013, Team WPI-CMU was provided with an Atlas humanoid robot, designed and built by Boston Dynamics specifically for the DRC. Atlas is a 150 kg humanoid robot with 28 hydraulically actuated degrees of freedom (DOF): 6 in each arm, 6 in each leg, 3 at the torso, and 1 in the neck. The form factor and the anthropomorphic design of the robot make it suitable to work in human environments and operate tools specifically designed for human use. In addition to load cells for force sensing at hands and feet and a fiber-optic inertial measurement unit (IMU) at the pelvis for estimating robot pose, each actuator on the arms has a linear potentiometer for position measurement and two pressure sensors to determine the joint forces based on differential pressure measurements. The robot's sensor suite also includes three IP (Ethernet) cameras to allow for a near 360° view of its surroundings and a Carnegie Robotics MultiSense SL sensor head which provides visual input to the operator. The MultiSense SL contains a set of stereovision cameras and a rotating LIDAR and can be used to produce a point-cloud to represent the robot view. The DARPA-developed Atlas robot has been upgraded in early 2015 to include a battery pack for on-board power and a new pump system. Atlas's upgrades also include new electrically actuated forearms with an additional wrist joint for improved dexterity (**Figure 1**). Even though the robot is designed to run untethered and without a safety line in the DRC Finals, in our laboratory experiments, the power is provided by a tether from a 480VAC supply. The Atlas is both mechanically and computationally powerful. It is equipped with three on board perception computers and a Wi-Fi link to a field computer for data processing. A Degraded Communications Emulator connects the Operator Control Stations to the robot through the field computer to emulate realistic signal-loss conditions during disasters. Team WPI-CMU's Atlas robot is equipped with three-fingered Robotiq hands that can be position, speed or force controlled. This selection is as a result of our detailed comparative study of three robotic hands provided to our team by DARPA [1].

Meeting the requirements of the DRC tasks using an Atlas humanoid robot has been the main research and development effort for our team. In this article, we highlight three aspects of human supervised control of the Atlas for non-conventional disaster response, the development of an optimization based full-body controller developed by our team, our model-based software design methodology for task completion and our approach to factoring tasks between the human operator and robot to maximize the utility of the human-robot team.

FULL-BODY CONTROL

At the DRC Trials in December 2013, the rough terrain task consisted of walking over inclines and then piles of cinder blocks, including tilted cinder blocks. In our initial tests, the walking and step controllers from Boston Dynamics were able to walk over much of the terrain, but not all of it. We therefore decided to develop our own walking controller [2]. Our analysis of the DRC Trials terrain task was that it was a "stepping stone" task, in that it required accurate foot placement. The robot's feet needed to be placed within the boundary of individual cinder blocks. We therefore developed a walking controller that focused on achieving known footstep targets, while footstep plans were automatically generated.

The full-body controller is implemented for the Atlas robot using quadratic programming to perform inverse dynamics and inverse kinematics. For each task, desired Cartesian motions for specific locations on the robot (e.g., foot, hand, and CoM) in the high-level controller are specified. The low-level controller takes these motions as inputs and computes physical quantities for each individual joint such as joint position, velocity, acceleration, and torque. Some of these outputs are then used as references in the joint level servos on the robot. Both inverse kinematics and inverse dynamics are formulated as quadratic programming problems, whose general form is given by

$$\begin{aligned} \min_{\mathcal{X}} \quad & 0.5\mathcal{X}^T G\mathcal{X} + g^T\mathcal{X}, \\ s.t. \quad & C_E\mathcal{X} + c_E = 0, \\ & C_I\mathcal{X} + c_I \geq 0. \end{aligned}$$

where X is the unknown and C_E, c_E, C_I, c_I are constraint coefficients which are problem specific.

The full-body controller was originally targeted at rough terrain bipedal walking and it has been redesigned to handle ladder climbing and full body manipulation. We also developed a state estimator to estimate pelvis translational velocity and Cartesian position. We used

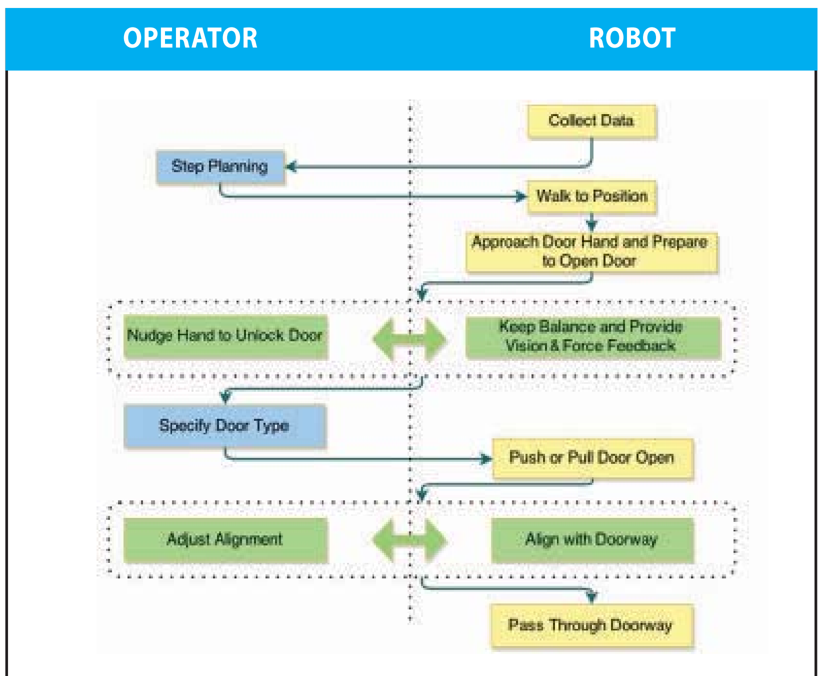

FIGURE 3 Action sequence demonstrating the factoring of the DRC Door Task between the robot and its operator.

the IMU orientation estimate directly. Based on which foot was on the ground, we used leg kinematics to provide us with a "measurement" of pelvis velocity and position. We used a simple Kalman filter to process this information.

The controller for ladder climbing at the DRC Trials was similar to our controllers for rough terrain walking and full body manipulation. The high-level control was provided by a manually generated script that implemented a quadruped climbing gait. The robot climbed one tread at a time. First the arms grasped a tread. Then one foot moved up one tread, followed by the other foot moving to the same tread. One arm moved up one tread, followed by the other arm. The DRC Finals will have a similar stair climbing task **(Figure 2)** which can now be completed using our walking controller.

One of our key decisions at the DRC Trials was to insert opportunities for a human operator to supervise hand and foot placement. In essence, the operator can position the robot limbs using small end-effector motions based on user keyboard inputs, called nudges. Nudges are 1 cm translations that can be commanded by the operator, moving the end-effector in the specified direction for effective human supervised step planning and manipulation. The robot would look at where the limb was supposed to go. The limb would move near to its target. The operator could use the keyboard to precisely place the limb with 1 cm increments horizontally, using visual feedback from the robot's cameras. This strategy worked quite well at the DRC Trials. Since then, for the full-body manipulation, we incorporated depth cameras at the robot wrists and implemented a visual servoing technique for manipulation tasks that require precision such as valve turning, operating a drill and door opening.

MODEL-BASED DESIGN

We adopt a model-based design (MBD) approach in our software development for task completion. MBD is a powerful design technique that emphasizes mathematical modeling to design, analyze, verify and validate complex dynamic systems in which physical processes and computation are tightly integrated. In completing disaster relevant manipulation and mobility tasks for the DRC, we use an iterative MBD approach to specify and verify requirements for each task, develop models for physical human and robot actions as well as the environment, select and compose models of computation, simulate the human-supervised system as a whole, and verify and validate the algorithm designs on the physical robot. To illustrate this approach we will focus on the DRC Door Task which is a key task to complete to enter the building and attempt all other manipulation tasks in the DRC Finals mission scenario.

We split the Door Task into four sub-tasks; door detection (DoorDetect), approach to the door (Approach), door opening (Open), and walk through the door (GoThrough). To maximize the utility of the human-robot team to complete this task, we developed a strategy for the door task in the DRC Trials. The key aspect to note is the factoring of the task between the human operator and robot as depicted in **Figure 3**. This factoring leverages the superior perception and decision-making capabilities of the human operator to oversee the feasibility of the steps planned in walking, selecting one of the three door types, and enabling the operator to make adjustments to robot actions to minimize errors. In the meantime, robot intelligence handles the balancing, motion planning and

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detection algorithms.

For the computation model, an event-driven finite state machine (FSM) with the sub-tasks as the states is used to control the autonomous execution of the process with human supervision and validation at critical steps. The first state in the FSM is DoorDetect which performs the door detection using a combined 2D and 3D segmentation technique to achieve successful detection of the door based on the geometric features. There is an option to do manual human detection if the algorithm does not converge in a certain time period. Once the normal vector to the door and the position of the door handle are calculated, FSM transitions to the Approach state. In this state, the robot follows a stepping trajectory generated by an A* planner and walks to the desired stand position for opening the door. The transition to Open state occurs when the robot fully executes the planned trajectory and comes to a stop in front of the door. The Open state is an FSM on its own and this structure demonstrates our approach to composition of the computational models in our approach. In the Open state, the robot will move the end-effector to a position suitable for manipulating the door handle; autonomous fine-tuning of the end-effector pose for grasping and turning the handle is achieved by visual-servoing using the depth camera on the wrist; the motion planner executes a trajectory for appropriate action to open the door (pull or push); and finally, the robot releases the door handle, and blocks the door from closing using its other arm. In the operation of this FSM, the operator supervises the process and has the ability to intervene to repeat an action or switch to a nudge state for manual fine-tuning of the motions to precisely position the robot end-effector. The final state in the FSM is GoThrough during which the path planner generates an optimal trajectory to go through the door using a dynamic artificial potential field.

A complete progression of the Door task is depicted in **Figure 4** in the simulation environment. As part of the MBD approach, validation of the algorithms designed to control Atlas in a physics-based simulation environment is critical before the algorithms can run on the actual robot. The simulation environment provides a means to test various scenarios, and techniques to complete each task. Once the human-robot system as a whole completes a task in simulation the code is tested on the physical robot. Our approach to the Door Task has proven to be effective

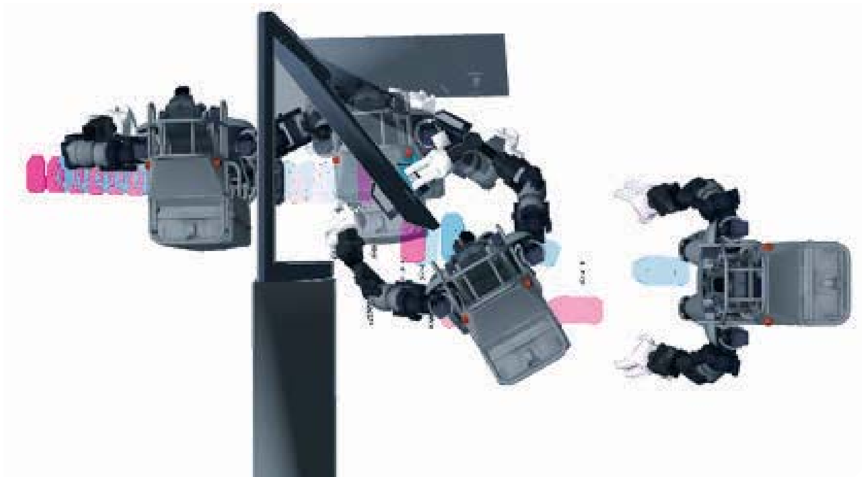

Figure 4 Simulation results demonstrating the door task progression.

as this is one of the tasks our team has the highest success rate (80%) to date. The challenge remains to complete the task within our time budget of 6 minutes. Our best completion time to date is 8 minutes.

CONCLUSION

In our recent research and development effort that focuses on realizing effective human-supervised humanoid robot control for non-conventional emergency response, we learned essential lessons. A persistent development effort is required to complete the DRC, and this comes sometimes at the cost of perfection. For example, the DRC Trials teams created simple yet effective solutions to hard manipulation problems such as turning on a drill using a shaking behavior, or opening a door using hooks.

Providing effective and easy to use human-robot interfaces is critical. Since the DRC poses realistically challenging operating conditions for the human, the interfaces need to have sufficient autonomy to minimize human errors. Last but not least, the factoring of the tasks between the human operator and the robot is an essential strategy to maximize the utility as a technical capability of the human-robot team. Making robots fully autonomous to complete challenging missions is still a work-in-progress. ■

2015 ASME DYNAMIC SYSTEMS AND CONTROL CONFERENCE

Columbus, OH
October 28-30, 2015

The eighth ASME Dynamic Systems and Control Conference (DSCC) will be held in Columbus, Ohio October 28-30, 2015. **Giorgio Rizzoni** and **Rama Yedavalli** from the Ohio State University will serve as general chair and program chair, respectively.

The DSC Conference, organized and led by the members of the ASME DSC Division, provides a focused and intimate setting for dissemination and discussion of the state of the art in the broad area of dynamic systems and control from theory to industrial applications and innovations in education. Location of ASME DSCC 2015 makes especially **manufacturing** and **automotive engineering** appropriate themes, which will be covered through special tracks.

Other special tracks will focus on the intersection between life sciences and engineering, as well as information technology in mechanical and aerospace engineering. The program will also include contributed sessions, invited sessions, tutorial sessions, special sessions, workshops, and exhibits.

Further details about the conference can be found at **http://www.asmeconferences.org/DSCC2015/**

Contributed by Giorgio Rizzoni (DSCC 2015 General Chair)

Photo Credit: Columbus skyline. Rod Berry/Ohio Stock Photography

BOSTON ACC 2016

2016 American Control Conference

BOSTON, MA, JULY 6-8, 2016

Led by General Chair **Danny Abramovitch** (Agilent Labs) and Program Chair **George Chiu** (Purdue University), the 2016 American Control Conference (ACC) will be held in Boston, Massachusetts, July 6-8, 2016.

The ACC is the annual conference of the American Automatic Control Council (AACC), the U.S. national member organization of the International Federation for Automatic Control (IFAC), and is co-sponsored by several other professional societies, including ASME, IEEE, IFAC, and SIAM among others.

Recognized internationally as a premier scientific and engineering conference, the ACC is dedicated to the advancement of control theory and practice, as well as control systems education. The 2016 ACC will bring together an international community of experts in these domains, within a high caliber technical program comprising regular and invited sessions, tutorial sessions, and special sessions along with workshops and exhibits.

Draft Manuscripts are due September 27, 2015.

Details can be found on the conference web site at http://acc2016.a2c2.org/index.html

Edited by Kam K. Leang (ACC 2016 Publicity Chair) and Rifat Sipahi

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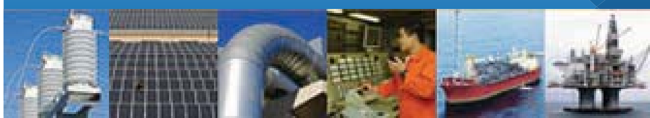
ASME
SETTING THE STANDARD

Energy Sources and Processing



From the Energy Sources and Processing Segment Board Chairman – June 2015

With great pleasure, I would like to introduce the newly formed Energy Sources and Processing (ESP) segment to my fellow ASME members, and provide an explanation on how the ESP segment fits within the reorganized ASME. For the past few years, I've proudly informed you of the many accomplishments of the former International Petroleum Technology Institute (IPTI), which has now evolved into the ESP segment. With this reorganization, I see even more opportunity for the ESP to serve the Society's missions and its global membership. Because the ESP model is quite similar and closely aligned with the previous IPTI model, we have adapted quickly and now, we are looking forward to serving the needs of the Society's members in ways that were not possible under the previous structure.

With our new model, we were able to bring the Pressure Vessels and Piping Division into the ESP fold to join the Petroleum Division (PD), the Piping Systems Division (PSD) and the Ocean, Offshore and Arctic Engineering Division (OOAE). These four divisions have always been active both locally and globally and will continue to be. In addition, we are now able to expand partnership opportunities with other similarly aligned ASME divisions within the ESP segment scope. To follow the activities of ESP, please visit the ESP segment group on ASME.org (https://community.asme.org/technical_events_and_content_sector/default.aspx).

The goal of the ESP segment is to engage groups and individuals that are developing mechanical engineering-related energy sources content spanning the complete lifecycle from raw state to end-customer. This includes energy sources, conversion from raw materials to fuels, or designing products, systems and services utilized in the energy sources and processing industries. ESP focuses on planning, developing and delivering technical events and content that is vital to the petroleum, natural gas, petrochemicals, coal, shale and LNG industries.

The ESP segment is aligned with ASME's mission statement in three core areas of energy, global impact and engineering workforce development. The division updates highlight our dedication to serving the local and global community by advancing, disseminating and applying engineering knowledge via technical workshops, conferences, presentations and training initiatives. The core strength of ESP, similar to the Society as a whole, is our committed and highly motivated corps of volunteers. These remarkable individuals leverage their strong technical skills and name recognition to achieve our ESP goals and ultimately, those of the Society. The division highlights summarize the growth and successes achieved over the past year. It is important, however, to recognize that our achievements were also due to our strong partnership with ASME staff.

WORLD-CLASS CONFERENCES & EVENTS

Conferences and events continue to form the foundation of the ESP segment activities that allow us to fulfill our ASME mission and goals. ESP's success is rooted in 18 highly successful conferences and events presented around the world. Of these, eight are "owned" by ASME and the remaining ten are co-sponsored by ASME. Many of these conferences and events have the potential for considerable growth. The ESP volunteers are market-focused and motivated and we will continue to identify new and different topics, events and conferences to broaden our reach and meet our markets' needs.

The success of the ESP segment conferences, events and training initiatives has drawn worldwide interest.

We are approached quite often to

(Continued next page)

host or partner on similarly aligned events. This is a testament to the power of the ASME brand and the global respect it garners — a direct result of the hard work that goes into organizing and staging world-class events by volunteers and staff. These events and conferences allow us to achieve the ASME goal of knowledge sharing through paper presentations and networking. Undoubtedly, you have heard of such signature annual events as the Offshore Technology Conference (OTC) in Houston, the Ocean, Offshore and Arctic Engineering (OMAE) conference, the Pressure Vessels and Piping Conference, and the biennial International Pipeline Conference (IPC) in Calgary. In addition, each ESP division hosts other events. I encourage you to visit www.asme.org (http://calendar.asme.org/) to learn more about them and to register.

The ESP segment continually looks for opportunities to add value for our members. This includes organizing events in partnership with other ASME segments to share knowledge across energy systems. In 2014, for example, we successfully partnered with another Society to co-sponsor an LNG conference that examined LNG lifecycle challenges, including unconventional natural gas extraction, transportation, and processing and offshore structures. In addition, we are currently organizing a Fall 2015 event with another ASME segment that includes the nuclear sector to focus on the critical issues of asset reliability and integrity. This diverse gathering of integrity and reliability specialists from many industrial sectors will serve to identify problems and solutions common to all.

The ESP segment volunteers continue to be committed and excited about the ever-expanding portfolio of technical engineering courses and workshops. The courses offered by the Divisions are designed to appeal to a broad audience, from entry-level engineers to senior engineers who seek more master-level knowledge. Due to past successes, the ESP segment is able to attract world-recognized subject matter experts to provide this training. In keeping with the Society mission statement of having a global impact and engineering workforce development, volunteer trainers come together to offer training affordable to our international community.

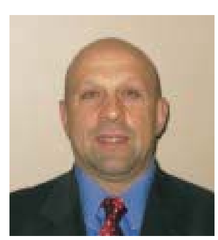
DEVELOPING YOUNG ENGINEERING TALENT

The ESP segment continues to address the impending shortage in engineering expertise. Numerous ESP volunteers deliver presentations to young students and sponsor teacher workshops. Our four divisions have proven track records of active and growing programs that engage engineering students and young professionals. These programs successfully communicate the attractions of the mechanical engineering field and the many benefits of ASME membership including networking opportunities, scholarship and internship programs, in addition to skill enhancement through training initiatives. These programs include the support and participation of the Collegiate Council and the sponsorship of student paper competitions at many of our conferences. All students are welcome at our events and we encourage their participation with significantly reduced registration fees.

If you are a student or young professional, I encourage you to join us and discover the career-enhancing opportunities available to you. For a complete list of our student programs and scholarships, including application forms, please visit asme.org (https://www.asme.org/about-asme/professional-membership/benefits-for-students). In addition, we are always looking for student volunteer leaders and are committed to providing you with the support you need to succeed.

The ESP segment and our divisions appreciate all of the time our tireless volunteers contribute to the Society and honor these contributions with awards that recognize exceptional volunteer and career effort. These awards include peer recognition of members who have helped advance the practice of engineering. And to help engineering students achieve their potential, we regularly award financial assistance in the form of scholarships. To learn more about these awards, please visit our website at asme.org (https://www.asme.org/about-asme/professional-membership/benefits-for-students).

We are excited about the ASME's ESP segment's future and encourage you to share your vision with us to help further the engineering profession. ■



Joe Pavigliantiti
Energy Sources and Processing Segment Chairman

The Petroleum Division Has a Great Year!

It has been an extremely busy year for the Petroleum Division. The Offshore Technology Conference (OTC) held annually in Houston has long been our signature event and this past year was no exception. With more than 108,000 attendees and more than 2,500 exhibitors, the 2014 OTC was one of the largest oil and gas industry conferences ever. Our division is always proud to host the ASME Best Mechanical Engineering Awards (BMEA) during the conference.

Other noteworthy 2014 PD events included holding the division's annual meeting in Killarney, Ireland; working with the Society of Petroleum Engineers (SPE) on the LNG event held in Vancouver, BC, in October; organizing a successful hydraulic fracturing event in March 2015 and participating in the Arctic Technology Conference in Copenhagen, also in March 2015.

EXPANDING THE COLLEGIATE COUNCIL PROGRAM & EARLY CAREERS

Our Collegiate Council Program has grown to 25 invited participants. These Junior and Senior level engineering students with professed interest in petroleum industry careers volunteer at ASME events to network as well as attend educational events as part of this popular program.

ASME Petroleum Division Collegiate Council visits the Ocean Star Offshore Drilling Rig and Museum in January 2015

This year, our Early Career network was occupied with several events including a quarterly technical industry presentation closely followed by networking opportunities. As evidenced by our 2014 activities, the Petroleum Division has strong student and early career programs designed specifically to help young engineers explore the oil and gas industry and discover the opportunities available to them. Our division members can help young engineers find their first job or the next best one, while they can tap the experience of seasoned industry colleagues.

A FULL SCHEDULE OF COMING EVENTS

We look forward to the upcoming events of 2015 including this year's OTC (May 2015) in Houston and the BMEA awards, OTC Brasil and a multi-divisional Integrity Management Workshop currently planned for October 2015 also in the Houston area. We are already engaged in advance planning for an OTC Asia in Kuala Lumpur, Malaysia, in 2016.

In closing, I look forward to working with all members of the Energy Sources and Processing Segment and across all of ASME for the betterment of not just the petroleum industry, but for all of society as well.

Kieran Kavanagh
Petroleum Division Chair
Group Technology Director
Wood Group Kenny
Galway, Ireland

Arthur Lubinski Best ASME Mechanical Engineering Paper Presented at OTC 2015

2015 WINNER

OTC 25643-MS

Next Generation HPHT Subsea Wellhead Systems Design Challenges and Opportunities

Jim Kaculi, D.Eng., P.E., Dril-Quip, Inc.

This paper was prepared for presentation at the Offshore Technology Conference held in Houston, Texas, USA, 4–7 May 2015.

Abstract

The oil and gas industry is targeting operations in much deeper waters and well depths resulting in high pressure and high temperature (HPHT) applications, creating a need for development of new technology to meet the challenges faced in these new frontiers. Considering the higher loads encountered in these environments, the existing industry equipment are reaching their limits and the manufacturing sector is looking into the development of the next generation equipment. Subsea wellheads form a critical part of the drilling and production systems, and they are the driver for designing and sizing other equipment, such as connectors, risers, BOPs, and casing programs. The typical wellhead systems that the industry currently uses include mandrels with 27 in. and 30 in. OD and conductor casing with up to 36 in. OD. However, these configurations may not be able to resist the high load magnitudes and combinations expected in these new applications. Moving to higher capacity wellhead systems will require a larger mandrel and conductor casing size to accommodate the high loads encountered during drilling and production operations for normal, extreme, and survival loading conditions. Considering the ongoing industry efforts to standardize equipment, it is a great opportunity to define the anticipated loads and select an appropriate larger wellhead size that will cover the needs of the industry for the coming decades.

Numerous analytical studies using 3D finite element analysis (FEA) and other advanced tools have been performed looking into the changes needed and an innovative solution is presented for the next generation subsea wellhead equipment. This is tied with the development of new wellhead connectors with much higher static capacities and the appropriate conductor sizes needed. Considerations are given to structural integrity, fatigue performance, and metal-to-metal sealing capability. Various load combinations (bending, tension/compression, pressure) were applied to generate the wellhead system capacity envelopes covering a wide range of operating windows. The need for the industry to define the anticipated normal, extreme and survival loading requirements and a standard set of fatigue loads is discussed. The fatigue performance and life expectancy of the equipment, as well as challenges faced with the lack of material properties at various HPHT environments are discussed.

Testing facilities to validate designs and safety margins at both component and system levels have been developed to accommodate the various high load magnitudes and their combinations. Validation testing is absolutely paramount to verify analysis methodologies and ensure high performance, safe, robust and reliable equipment designs.

2015 Lubinski Paper Nominees

1st Runner-up

OTC 25850 Daniel Hiller, Developing An Innovative Deepwater Riser System: From Concept To The Full Production of Buoy Supporting Risers (bsr)

2nd Runner-up

OTC 25832 Ivan Cruz, The New Technology Enablers Developed And Deployed On A Live Project

3rd Runner-up

OTC 25717 Dan Fraser, Hydro-rest Rick Minimization Through Design And Processing For Subsea HP/HT Well Equipment

4th Runner-up

OTC 25889 Colin Stevenson, Development And Execution Of A Wax Remidiation Pigging Program For A Subsea Oil Export Pipeline

5th Runner-up

OTC 25729 Amadeu Sum, Multiphase Flow Modeling For Gas Hydrates In Flow Assurance

Introducing the First ASME Integrity Management in Energy Workshop

October 4-6, 2015
La Torretta Lake Resort & Spa
Lake Conroe (outside Houston), Texas

This first ever multi-divisional program is designed to share best practices and provide insight into key integrity management and associated topics, including failure analysis and integrity of designs for the full life cycle of products, processes and systems.

Benefits to all participating groups and attendees will include:

- Unique content focused on bringing specific disciplines together to learn as a team
- An interactive platform to identify and solve integrity management problems
- A premier marketplace of ASME groups for innovative technology exchange between vendors and users

Track topics will include:

- Process safety
- HSE and integrity management relationship
- Integrity management advances in data mining and real time monitoring
- Best practices from codes and standards in energy and non-energy industries
- Discipline-specific tracks: pipelines, nuclear, power, pressure vessels & piping and petroleum

For additional information or to participate, please contact:
Jamie Hart, Manager
Conferences & Events,
ESP Segment
hartje@asme.org

ASME 2015 Hydraulic Fracturing Conference

March 17-19, Houston

The conference focused on the central role of mechanical engineering in shale development and hydraulic fracturing. The outstanding three-day conference delivered cutting-edge solutions for operations; specifically the construction, delivery and production of unconventional wells, associated infrastructure and applied solutions. It also provided its 333 attendees with expert insights into the technological, economic and regulatory trends driving this industry.

Two workshops were conducted: Hydraulic Fracturing 101 and Hydraulic Fracturing: Water Issues and Opportunities. Three panel sessions featured four keynote speakers including Paula Gant (U.S. Department of Energy), David J. Porter (Texas Railroad Commission) and David Miller (API). The conference also presented a total of 10 sessions with 42 speakers and 16 e-poster presentations.

Check www.asme.org for upcoming information on the 2016 Hydraulic Fracturing Conference. ■

ASME President J. Robert Sims opens the Conference

Martin Rylance
BP
Conference Chair

Jared Oehring
U.S. Well Services
Conference Co-Chair

Panel Session at Hydraulic Fracturing (left to right):
Paula A. Gant, Deputy Assistant Secretary, Oil and Natural Gas, Office of Fossil Energy, U.S. Department of Energy; David Miller, Director, Standards Program, American Petroleum Institute (API); David J. Porter, Commissioner, Texas Railroad Commission; Frank C. Adamek, P.E., Chief Consulting Engineer GE Oil & Gas Drilling & Surface.

From the Pipeline Systems Division Chair – April 2015

A highlight of our year was the biennial International Pipeline Conference held last fall in Calgary, which has grown in terms of attendance and paper submissions. This past year, two associated special events included the award of the Pipeline Systems Division (PSD) medal to our division's first chairman and industry leader, Dr. Alan Murray, as well as the publication of a commemorative collection of the best papers presented at past conferences. Also of particular note for 2014 were two highly successful PSD-sponsored conferences held in India and Colombia.

This year, I'd like to note that our division benefits from the continued contributions of our past chairmen, who are also leaders within the pipeline industry, and from the efforts and dedication of our membership. An example of such leadership and dedication is Rafael Mora, Pipeline and Distribution Integrity Advisor, Imperial Oil Canada, who has worked tirelessly to organize what is now the biennial International Pipeline and Geotechnical Conference to be held in July 2015 in Bogota, Colombia.

PROMOTING UPCOMING ENGINEERING TALENT

Our division is committed to supporting new, potential and student mechanical engineers who are interested in careers focused on the pipeline industry. We support the established Young Pipeliners Association of Canada (YPAC) and the rapidly growing US-based Young Pipeline Professionals (YPP). We urge students and early-career MEs to consider the pipeline industry as a career choice and to network through involvement with the YPAC and YPP. The energy transmission pipeline sector is a dynamic arena for engineers, both young and seasoned. By becoming active within the PSD, pipeline engineers are tapping into career-enriching opportunities to network, transfer knowledge and socialize with enthusiastic and respected peers in the industry.

Moness Rizkalla
Pipeline Systems Division
WorleyParsons

The ASME Pipeline Systems Division's Global Pipeline Award (GPA) recognizes outstanding innovations and technological advances by various organizations in the field of pipeline transportation. The following finalists and winners were honored at the ASME Awards Dinner at this past year's IPC.

The 2014 GPA Winner
Penspen & Northumbria University for their MSc in Pipeline Integrity Management Distance Learning Program. For more information visit: http://www.penspen.com/capabilities/services/training-education/distance-learning/

2014 GPA Finalists

- Magnatech International for the Hartweel Project, Oman.
- Hunter McDonnel Pipeline Services, Inc., for the Armadillo Remote Tracking Unit
- Transcanada for the Tamazunchale Extension Pipeline Project
- Enerco S.p.A. for TPR Trenchless Pipeline Removal

Past Pipeline Systems Division (PSD) Chairs and recent Fellows were also recognized.

Past Chairs
Pat Vieth, 2010 - 2011
Joe Paviglianiti, 2011 - 2012
Bill Byrd, 2012 - 2013
Taylor Shie, 2013 – 2014, Immediate Past Chair

ASME PSD Fellows
Marcelino Gomes
Kevin Bodenhamer, P.E.
Mike Yoon, Ph.D.

In addition, Rafael Mora was named PSD Exceptional Volunteer for his work in establishing the International Pipeline Geotechnical Conference and the associated Recommended Practice Document. Dr. Alan Murray, founder of the Pipeline Systems Division, received the first Pipeline Systems Division Medal. This award recognizes excellence in engineering and service to the ASME PSD.

To learn more about the GPA program, please contact Kim Miceli at micelik@asme.org or visit http://www.internationalpipelineconference.com/conference/global_pipeline_award.php

PSD Conferences

ASME SETTING THE STANDARD

ASME 2015 INDIA

INTERNATIONAL OIL & GAS PIPELINE CONFERENCE

Shangri-La's - Eros Hotel, New Delhi

April 17-18, 2015

ASME 2015 India Oil & Gas Pipeline Conference

The 5th biennial ASME 2015 India Oil & Gas Pipeline Conference was held on April 17-18, 2015 in Delhi, India.

The Conference was designed to share technical knowledge and introduce new initiatives in the oil & gas industry in India. Based on feedback from prior conference attendees, the following technical topics were presented. All papers were peer reviewed and published by ASME.

Track 1 – Design And Construction (Onshore/Offshore) – Oil & Gas
Track 2 – Materials For Pipelines
Track 3 – Integrity Management – I
Track 4 – Integrity Management – II (Pipeline Operation and Maintenance)
Track 5 – Health, Safety and Environment (HSE)
Track 6 – Challenges In Pipeline & CGD Industry

2015 Steering Committee Leaders

Conference Chair: Dr. Ashutosh Karnatak, Director – Projects, GAIL
Conference Vice-Chair: J. P. Ojha, Executive Director – Projects, IOCL (Pipelines Div.)
Conference Technical Chair: Mr. Narendra Kumar, Managing Director, IGL

For more information please contact Kim Miceli at micelik@asme.org or visit the conference website: http://www.asmeconferences.org/IOGPC2015/index.cfm

PSD Conferences

International Pipeline Geotechnical Conference

July 15 – 17, 2015
Bogota, Colombia

ASME, together with la Asociación Colombiana de Ingenieros (ACIEM) and the Regional Association of Oil, Gas and Biofuels Sector Companies in Latin America and the Caribbean (ARPEL), is pleased to announce the second biennial International Pipeline Geotechnical Conference to be held July 15 – 17, 2015 in Bogota, Colombia.

This biennial conference is an international event developed to promote knowledge sharing, technological progress and international cooperation for advancing the management of natural forces impacting pipelines. Its mission is to protect the public, environment and energy infrastructure assets, and to ensure safe and reliable operations.

The practice of geohazard management, defined as special design and construction, monitoring and inspection, risk assessment and associated data management, has seen considerable advancements in recent years as recognition of the impact of such geohazards has increased. These risk factors, that arise during pipeline construction and operations, can be classified as geotechnical, geological, hydrological or tectonic, and represent critical issues in the integrity management of pipelines due to the occurrence of failures that have caused loss of human life and damage to the environment.

The pipeline risk factors associated with natural forces include

- Landslides and mass movement
- Tectonics/seismicity — including fault crossings and liquefaction
- Hydrotechnical — including river scour and channel migration
- Erosion and upheaval displacement
- Geochemical — including karst and acid rock drainage
- Unique soil structure — including residual and sensitive soils
- Desert mechanisms — including dune migration
- Volcanic mechanisms
- Ground freezing
- Thawing of permafrost terrain

A Recommended Practice document is currently being developed based on the proceedings of the prior IPG conference held in 2013. The official language of the conference is English; however, papers submitted in Spanish and Portuguese will be accepted and translated.

Please visit the conference website for further information: http://www.asmeconferences.org/ipg2015/■

Track 1 – Geohazard Considerations for Design and Construction
Track 2 – Geohazard Risk Assessment and Pipeline Integrity Management Planning
Track 3 – Monitoring, Mitigation and Emergency Repairs
Track 4 – Poster Papers

OCEAN, OFFSHORE AND ARCTIC ENGINEERING DIVISION

From the Ocean, Offshore & Arctic Engineering Chair – April 2015

Under the leadership of Dr. Mehernosh Irani, chair of the OOAE division through June 30, 2014, the 33rd International Conference on Ocean, Offshore & Arctic Engineering (OMAE) was a resounding success. The conference, held in San Francisco, June 8 - 13, 2014, was expertly chaired by Prof. Ronald W. Yeung of the University of California at Berkeley and co-chaired by Dr. Dominique Roddier, Marine Innovation & Technology. Dr. Owen Oakley chaired the Technical Program. More than 1200 participants attended the conference and approximately 900 technical papers were presented. In addition, more than 40 students participated in OMAE 2014 proving the conference's outreach program quite successful as well.

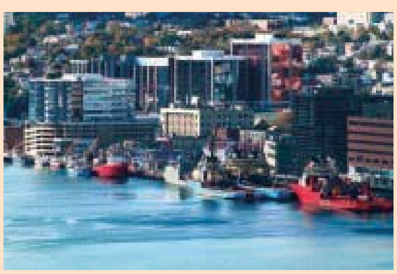
We're looking forward to the 34th International Conference on Ocean, Offshore & Arctic Engineering. Scheduled to be held May 31 –June 6, 2015 in St. John's, Newfoundland, OMAE 2015 will be chaired by Dr. Wei Qu of Memorial University, I will serve as co-chair and the Technical Program will be chaired by Dr. Mehernosh Irani. The conference will comprise 12 Technical Symposia with more than 800 technical presentations and 1000 attendees.

To young engineering professionals, potential members and students who are interested in OOAE careers, we encourage you to attend the OMAE conference, talk to our volunteers, and get to know the experts who work so hard to provide relevant technical forums for the good of the ocean, offshore and arctic engineering industry and community.

We would like to thank all the people noted above, plus all our volunteers, for all their hard work in making all our division conferences and events such shining successes. Without their diligence and dedication the success of our organization would not be possible.

Charles Smith
Ocean, Offshore & Arctic Engineering Division

OMAE 2015



St. John's, Newfoundland, Canada
May 31 – June 5

Industry, academia and government came together at the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2015) in St. John's, Newfoundland, Canada from May 31 - June 5, 2015. The conference provided an ideal forum for researchers, engineers, managers, technicians and students to meet and present advances in technology and scientific support, exchange ideas and experiences while promoting technological progress, and to promote international cooperation in ocean, offshore and arctic engineering. Following on the tradition of excellence established by previous OMAE conferences such as OMAE 2014 with 1,260 participants from 45 countries with a total of 914 papers published, more than 900 technical papers were presented at OMAE 2015.

FUTURE OMAE CONFERENCES:

2016 – Busan, Korea.
2017 – Trondheim, Norway.

Is your city interested in hosting OMAE in the future? Contact Javanni Kiezer at kiezerj@asme.org for information.

OCEAN, OFFSHORE AND ARCTIC ENGINEERING DIVISION

9th Outreach for Engineers Specialty Forum at OMAE

The Ocean, Offshore and Arctic Engineering Division (OOAE) of ASME hosted a specialty forum at OMAE 2015. The specialty forum was designed for both students and early professionals not familiar with the industry, as well as those who are. This is the ninth year of the Outreach for Engineers Forum. Highlights of the Forum included:

- Presentations of various technologies, such as ocean and/or offshore engineering, civil engineering, petroleum engineering, aerospace engineering, mechanical/structural engineering and project management
- Job opportunities
- Possible career paths
- Team building activities

In addition, Outreach for Engineers Specialty Forum delegates were provided with the opportunity to participate at the 34th International Conference on Ocean, Offshore and Arctic Engineering as full conference delegates. This conference showcased more than 900 technical papers from engineers and scientists from around the world and 12 symposia representing the range of technologies.

Through the generosity of our sponsors and the OOAE Division, attendance scholarships were made available to qualified students and early professionals.

You can find further information about the Outreach program here: http://www.asmeconferences.org/OMAE2015/Outreach.cfm ■

PRESSURE VESSELS & PIPING DIVISION

Pressure Vessels & Piping Joins ASME's Energy Sources & Processing Segment

For Pressure Vessels & Piping, 2014 was an extraordinary year. In addition to our outstanding annual PVP Conference, held last July in Anaheim, California, ASME reorganization opened new avenues for our division to collaborate with the others within the Energy Sources & Processing and Energy Sources & Conversion Segments, as well as others. We expect this new collaboration with our partner divisions to strengthen our capabilities, enable growth and allow us to continue providing outstanding technical content and mentorship.

The 2014 PVP Conference mentioned above featured plenary talks regarding High Pressure High Temperature (HPHT) applications and design guidelines in development in the subsea oil and gas markets, as well as technical forums and exhibits on Non-Destructive Evaluation (NDE) and advanced software applications. In all, there were 1100 registrants from 37 countries, 179 technical sessions, one technical workshop and several tutorials.

GLOBAL OUTREACH & COLLABORATION

New initiatives and global outreach continue to be noteworthy endeavors for our division. We are working diligently to identify and strengthen our portfolio of content and events. Some new events of note include cross-sector collaboration with the Standards and Certification sector to host a Post-Construction Committee (PCC) Workshop as part of the 2015 PVP conference. This one-day workshop will include an overview of all the current post-construction standards, along with break-out panel sessions for the discussion of

(Continued next page)

future direction and opportunities for enhancement of standards. Our division is also participating along with our partner divisions in the Energy Sources & Processing segment to develop the Integrity Management in Energy workshop to be held outside Houston on October 4-6, 2015. This event will cover integrity management, failure analysis and lifecycle management.

TAKING THE INITIATIVE…

The reorganization that occurred within ASME this past year, including the creation of the Technical Events and Content sector continues to evolve. Accordingly, PVP is adapting and changing as needed. In addition to the "behind the scene" changes to the normal business operations of the division, we are in the process of developing many new initiatives, new events and opportunities for our membership and the PVP industry as a whole. We are also continuing close collaborating with the Board on Pressure Technology Codes and Standards (BPTCS) of the Standards and Certification sector, and continue to look for innovative ways to enhance the relationship and support the efforts of ASME as the world leader in standards development.

THANKS AND REMEMBRANCES

As Chair of the PVP Division, I would like to extend a special note of thanks to all who are currently involved in planning for the 2015 PVP Conference. This includes Dr. Marina Ruggles-Wrenn, the Conference Chair, Dr. Doug Scarth, the Technical Conference Chair, and Ron Hafner, the head of the Student Paper Competition, as well as all of the Technical Committee Chairs, Technical Program Chairs, Session Developers and Authors who continue to make PVP one of ASME's premier technical conferences.

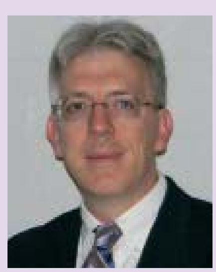
This past year, we lost two of our leaders — Dr. Robert Nickel, past ASME President and past PVP Division Chair, and Dr. Luc Geraets, past Division Chair and Vice President of the former Knowledge and Communities sector. Their leadership and friendship will be sorely missed.

FOR OUR YOUNG PROFESSIONALS AND STUDENTS

New and student members are encouraged to become involved in our many activities. For students interested in PVP-related careers, we are offering the 23rd annual Rudy Scavuzzo Student Paper Competition at PVP 2105. This is a terrific opportunity to showcase your research and development work while interfacing with colleagues and potential employers. The competition includes a travel allowance for attending and presenting at the conference and monetary awards for both the BS/MS and PhD categories. The PVP Conference also offers a great number of networking and educational opportunities. You'll rub elbows with experts in such areas as Codes & Standards, Fitness for Service, design, advanced materials, fluid structure interaction, high pressure technology and many other specializations.

A BRIGHT FUTURE

Our division will continue to be a leader within ASME. New programs, initiatives and leveraging technology and knowledge will allow us to continue to grow and provide outstanding technical content. Our future looks bright for our energetic and dedicated membership. ■



Daniel T. Peters
Pressure Vessels & Piping Division Chair
Associate
Structural Integrity Associates, Inc.
Edinboro, PA

2015 ASME Pressure Vessels & Piping Conference

Boston Park Plaza
July 19-23, 2015

New Frontiers in Pressure Vessels and Piping

The ASME 2015 PVP Conference promises to be an outstanding international technical forum. Participants will have the opportunity to increase their knowledge base and freely exchange ideas and opinions amongst industrial and academic experts in pressure vessel and piping technologies for the power and process industries. The PVP division is anticipating lively technical exchanges and a diverse attendance with participants from Europe, Africa, the Middle East, Asia, the Americas and the Oceania islands.

The ASME Pressure Vessels and Piping Division is the primary sponsor of the PVP-2015 Conference, with additional participation by the ASME Nondestructive Evaluation Engineering (NDEE) Division. More than 175 paper and panel sessions are planned, as well as workshops, tutorials, NDEE and Software Demonstration Forums, and the Rudy Scavuzzo Student Paper Competition & Symposium.

General topics and conference highlights will include:

- Codes & Standards
- Computer Technology & Bolted Joints
- Design & Analysis
- Fluid-Structure Interaction
- High Pressure Technology
- Materials & Fabrication
- Operations, Applications, & Components
- Seismic Engineering
- Non-Destructive Examination
- The Rudy Scavuzzo Student Paper Competition and Symposium

For further information on the PVP Conference contact Jamie Hart at hartje@asme.org or contact the conference organizers listed below:

PVP Conference Chair:
Marina Ruggles-Wrenn
Air Force Institute of Technology
ruggleswrenn@gmail.com

Technical Program Chair:
Douglas A. Scarth
Kinectrics Inc.
doug.scarth@kinectrics.com

Sponsorship Opportunities:
Carl E. Jaske
Det Norske Veritas
carl.jaske@dnvgl.com

For more information regarding the 2015 ASME PVP Conference, please visit the conference website at http://www.asmeconferences.org/PVP2015/index.cfm

2015 – 2017 Technical Conferences & Expositions

2015

Offshore Technology Conference
May 4 – 7
Houston, Texas

International Conference of Ocean, Offshore and Arctic Engineering
May 31 – June 5
St. John's, Newfoundland, Canada

2015 Power and Energy Conference
June 28 – July 2
San Diego, California

International Geotechnical Pipeline Conference
July 15 – 17
Bogota, Colombia

|*ASME 2015 Pressure Vessels & Pipeline Conference*
July 19 – 23
Boston, Massachusetts

Rio Pipeline Conference
September 22 – 24
Rio de Janeiro, Brazil

ASME Integrity Management in Energy Workshop
October 4 – 6
Houston, Texas

OTC Brasil
October 27 – 29
Rio de Janeiro, Brazil

2016

ASME Hydraulic Fracturing Conference
Houston, Texas

2016 Banff Pipeline Workshops
Banff, Alberta, Canada

OTC Asia 2016
Kuala Lumpur, Malaysia

Offshore Technology Conference
Houston, Texas

Arctic Technology Conference 2016
St. John's, Newfoundland

2017

India Oil & Gas Pipeline Conference 2017
New Delhi, India

Educational & Networking Events

International Offshore Pipeline Lunch and Learns (quarterly)
Houston, Texas

Annual ASME OTC Golf Tournament
April 30, 2016
Houston, Texas

Early Career Mixers
Houston, Texas

Annual ASME Sporting Clays Tournament
October 16, 2016
Houston, Texas

2015 – 2016 OTC Events

May 4-7
Offshore Technology Conference
NRG Park, Houston

October 27-29
OTC Brasil
Rio de Janeiro

March 22-25, 2016
OTC Asia
Kuala Lumpur, Malaysia

October 2016
OTC Arctic Technology Conference
St. John's, Newfoundland

ASME HAS BEEN DEFINING SAFETY FOR PIPELINES AND PIPING SINCE 1922.
Our portfolio of B31 Codes prescribe minimum requirements for the design, materials, fabrication, erection, test, inspection, operation, and maintenance of piping systems found across a wide range of industries.

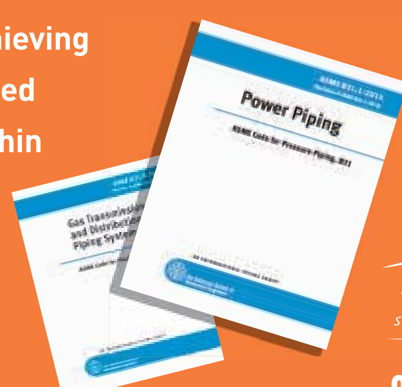
ASME'S B31 CODES:

Essential requirements for construction of pipelines and piping

These B31 Codes have been updated by industry experts to meet the needs of fast-changing markets:

- **B31.1** — POWER PIPING — NEWLY REVISED!
- **B31.3** — PROCESS PIPING — NEWLY REVISED!
- **B31.8** — GAS TRANSMISSION AND DISTRIBUTION PIPING SYSTEMS — NEWLY REVISED!
- **B31.8S** — MANAGING SYSTEM INTEGRITY OF GAS PIPELINES — NEWLY REVISED!
- **B31.12** — HYDROGEN PIPING AND PIPELINES — NEWLY REVISED!
- **B31Q** — PIPELINE PERSONNEL QUALIFICATION — NEWLY REVISED!

Keep current with the latest technology...while achieving the operational, cost, and safety benefits to be gained from the many industry best-practices detailed within these volumes. ASME also offers related training courses, technical publications, and professional conferences to help you keep current with these B31 Codes. Learn more at go.asme.org/B31.



ASME
SETTING THE STANDARD

GO.ASME.ORG/B31

The American Society of Mechanical Engineers (ASME)

Standards in development include one for glass-fiber-reinforced industrial piping.

THESE PIPES HAVE PASSED

ASME STANDARDS IN DEVELOPMENT FOR NON-METALLIC PIPING AIM TO PROVIDE A UNIFORM APPROACH TO WHAT IS NOW A CUSTOMIZED PRODUCT.

BY COLLEEN O'BRIEN, NOEL LOBO, AND CARLTON RAMCHARRAN

IT IS NO SURPRISE THAT NON-METALLIC PIPING IS GAINING FAVOR FOR HANDLING FLUIDS IN PROCESS PLANTS AND PIPELINES. Non-metallic piping generally weighs less and is potentially less costly than comparable metallic piping. What's more, most non-metallic materials resist corrosion that can shorten the life of metals.

A barrier to wider adoption of the material has been the absence of non-metallic piping standards that could serve as a common language for manufacturers, fabricators, designers, and other stakeholders. While various standards have begun to address the use of non-metallic materials in industrial piping, they do not provide adequate requirements to cover the service limitations, design, materials, fabrication, installation, fusing or joining, and quality control of non-metallic piping systems.

Beginning a century ago with the Boiler and Pressure Vessel Code, these are the issues in which ASME has excelled as a standards development organization. That's why ASME has turned its attention to non-metallic piping and expects to publish its first set of standards covering the subject in late 2016 or early 2017.

Standards for non-metallic piping systems are significantly different from those applicable to piping made of steel and other metals, and the development of rules for non-metallic materials requires a unique set of expertise. Accordingly, ASME assembled the Committee on Non-metallic Pressure Piping Systems (NPPS) in 2011 for the purpose of formulating standard rules for the construction of non-metallic pressure piping systems.

The committee and its subordinate groups are composed of stakeholders from different industries with expertise in dealing with a wide range of non-metallic materials. As with most ASME standards committees, members represent widely differing perspectives. They include designers, manufacturers, operators, insurers, and regulators.

The standards under the scope of the committee will cover the design, manufacture, fabrication, installation, examination, testing, and inspection of thermoplastic and glass-fiber-reinforced thermosetting resin piping systems suitable for pressure applications. They will also cover specifications for non-metallic materials (other than wood, glass, and concrete) for pressure applications including material design values and limits on the use of non-metallic materials.

Currently, designers, fabricators, installers, owners, and others in the industry develop a wide variation of customized designs among the suppliers of these products. The standards developed under the NPPS Standards Committee will provide uniform quality control of materials and dimensions of the associated piping components and will enhance safety by promoting interchangeability and reliability of systems.

The NPPS Committee is currently developing three standards: ASME NM-1 Standard on Thermoplastic Piping, ASME NM-2 Standard on Glass Fiber Reinforced Thermosetting Resin Piping, and ASME NM-3 Standard on Non-metallic Materials.

The intent of ASME NM-1 is to set engineering requirements for safe design and construction of thermoplastic piping installations. It covers pipe, flanges, bolting, gaskets, valves, fittings, special connecting components, and the pressure-containing portions of other piping components. It will also include hangers and supports and other equipment items necessary to prevent overstressing the pressure-containing components.

The temperature limits for each thermoplastic material will contain a maximum continuous-operating temperature and pressure and a maximum short-term operating temperature and pressure for a given time.

Engineering requirements of this standard, while considered necessary and adequate for safe design, generally use a simplified approach. A designer may choose to apply a more rigorous analysis, but the approach must be documented and accepted by the owner.

At present, engineering companies designing this equipment for electric power generating plants have difficulty justifying their designs using existing standards. ASME B31.1 and ASME B31.3 limit the pressure in thermoplastic piping systems to 150 psi at 140 °F. However, there are applications for thermoplastic piping systems above 150 psi at a wide range of temperatures. The NM-1 Standard will provide realistic temperature and pressure ranges for using thermoplastic piping systems.

ASME NM-2 will provide requirements for the design, materials, manufacture, fabrication, installation, examination, and testing of glass-fiber-reinforced thermosetting resin piping systems. In industrial use, this type of piping is commonly referred to as FRP piping. The abbreviation stands for "fiberglass reinforced plastic."

"There are a number of FRP product standards available in the industry that provide procedures for designing products for pressure containment," said Bruce Hebb, vice president of engineering at RPS Composites in Mahone Bay, Nova Scotia, and a member of the NM-2 Subcommittee, "but there is very little direction on how to properly analyze FRP piping systems. The most common type of FRP pipe, i.e. pipe that is filament wound at 55 degrees to the pipe axis, displays significantly different axial strengths depending on whether the stress is due to pressure or due to other loads, such as bending due to weight loading. Proper analysis of the piping must recognize that behavior so as to achieve a consistent margin of safety under various loading conditions.

"It is also necessary to recognize that FRP is not a ductile material: it does not shake down to elastic behavior," Hebb said. "So it is not appropriate to deal with displacement-induced loadings in the same way as is done for ductile materials. The new ASME FRP pipe standard will address these very important issues. Adherence to the requirements of the Standard will provide greater confidence in the safety of FRP piping, and greater reliability of FRP piping systems."

Like the ASME NM-1 Standard, NM-2 will address pipe and piping components which are produced as standard products, as well as custom products designed for specific applications. This standard also includes hangers and supports and other equipment necessary to prevent overstressing the pressure-containing components. In addition, the ASME NM-2 standard will cover piping and piping components manufactured by contact molding, centrifugal casting, filament winding, and other methods.

Present rules for FRP Piping are found in ASME B31, RTP-1, and BPV Codes in which they only address rules for reinforced thermoset plastic corrosion-resistant equipment, and none specifically for pipe and piping components or other non-metallic product forms. The Boiler and Pressure Vessel Code Section III has a few Code Cases that address rules for selected non-metallic piping and components including fiberglass reinforced plastic and selected thermoplastics such as high density polyethylene and polyvinyl chloride. However, in some of these cases, this represented old methodology.

Similar to the function that Section II of the Boiler and Pressure Vessel Code serves for metallic materials, ASME NM-3 will provide a repository for allowable stress values and physical properties of non-metallic materials. Initially NM-3 will specifically support the NM-1 and NM-2 construction standards, but the long-term vision for NM-3 is to support ASME construction codes including the Boiler and Pressure Vessel Code, B31 Pressure Piping, B16 Valves, Flanges, Fittings, and Gaskets, and Reinforced Thermoset Plastic Corrosion Resistant Equipment.

At present, the design of non-metallic piping systems requires the designer to rely heavily on manufacturer-specific material properties and suggested allowable stress values. As a result, a complete set of required properties is not always readily available and suggested values can vary significantly between manufacturers. Additionally, the bases of and inherent margins in the allowable stress values are not always well defined. Collectively, these differences can result in wide variations from one system to another in overall design margin.

ASME NM-3 will provide a complete set of required physical properties and allowable stress values for many non-metallic materials in a consistent format, along with clearly defined bases for these properties and values. The NM-3 standard will also include numerous non-metallic material specifications for this initial set of materials and will lay out a robust process for including additional non-metallic materials in future editions. The NM-3 Standard intends to provide greater uniformity, consistency, and transparency for the identification and establishment of physical properties and allowable stress values for materials in non-metallic piping systems.

"ASME codes and standards have become the gold standard for the design and construction of metallic pressure vessels and piping systems throughout North America and around the world," said Thomas Musto of Sargent & Lundy LLC in Chicago. Musto serves as chairman of the NM-3 Subcommittee. "The ASME Non-metallic Pressure Piping Systems Code looks to build on this tradition of excellence by expanding the scope of ASME codes and standards to provide end users with a robust approach for design and construction of non-metallic piping systems."

The development of the new standards also reflect the growing international role of ASME standards. According to Mohinder Nayyar, chairman of the NPPS Standards Committee 2011-2014, the committee is considering best practices and requirements from various international references, in addition to sources in the United States.

The standards for thermoplastic and FRP piping systems are being developed to fill the unmet need for comprehensive documents in these areas. The committee expects them to gain acceptance in both the domestic and international industry. **ME**

COLLEEN O'BRIEN is a project engineer, **NOEL LOBO** a project engineering advisor, and **CARLTON RAMCHARRAN** an engineer in the Pressure Technology Department of ASME Standards & Certification.

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PD570	Geometric Dimensioning and Tolerancing Fundamentals 1	16-17 Aug
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PD506	Effective Management of Research & Development Teams & Organizations	16-18 Aug
PD643	B31.3 Process Piping Code ASME STANDARDS COURSE	16-19 Aug
PD725	BPV Code, Section VIII, Division 1: Design and Fabrication with Inspections, Repairs and Alterations of Pressure Vessels ASME STANDARDS COURSE	16-20 Aug

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SEPT. – OCT. 2015 – LAS VEGAS, NEVADA USA

PD391	ASME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids ASME STANDARDS COURSE	28-29 Sep
PD445	B31 Piping Fabrication and Examination ASME STANDARDS COURSE	28-29 Sep
PD570	Geometric Dimensioning and Tolerancing Fundamentals 1 ASME STANDARDS COURSE	28-29 Sep
PD410	Detail Engineering of Piping Systems NEW!	28-30 Sep
PD615	BPV Code, Section III, Division 1: Class 1, 2 & 3 Piping Design ASME STANDARDS COURSE	28-30 Sep
PD631	Manufacturing, Fabrication and Examination Responsibilities in Codes, Standards & Regulations for Nuclear Power Plant Construction ASME STANDARDS COURSE	28-30 Sep
PD763	Centrifugal Pumps: Testing, Design and Analysis NEW!	28-30 Sep
PD184	BPV Code, Section III, Division 1: Rules for Construction of Nuclear Facility Components ASME STANDARDS COURSE TOP SELLER	28 Sep-1 Oct
PD359	Practical Welding Technology	28 Sep-1 Oct
PD448	BPV Code, Section VIII, Division 2: Pressure Vessels ASME STANDARDS COURSE TOP SELLER	28 Sep-1 Oct
PD603	GD&T Combo Course (combines PD570 and PD561) **SAVE UP TO $825!**	28 Sep-1 Oct
PD675	ASME NQA-1 Lead Auditor Training	28 Sep-1 Oct
PD192	BPV Code, Section XI: Inservice Inspection of Nuclear Power Plant Components ASME STANDARDS COURSE	28 Sep-2 Oct
PD432	Turbo Machinery Dynamics: Design and Operation	28 Sep-2 Oct
PD561	Geometric Tolerancing Applications and Tolerance Stacks	30 Sep-1 Oct
PD621	Grade 91 and Other Creep Strength Enhanced Ferritic Steels	30 Sep-1 Oct
PD531	Leadership and Organizational Management	1-2 Oct
PD673	Design and Selection of Heat Exchangers	1-2 Oct
PD692	Communication Essentials for Engineers NEW!	1-2 Oct

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OCTOBER 2015 – MIAMI, FLORIDA USA

PD100	Introduction to the Maintenance and Inspection of Elevators and Escalators	12-13 Oct
PD475	The Engineering Manager: Engaging Today's Workforce	12-13 Oct
PD567	Design, Analysis and Fabrication of Composite Structure, Energy and Machine Applications	12-13 Oct
PD606	NQA-1 Requirements for Computer Software Used in Nuclear Facilities ASME STANDARDS COURSE	12-13 Oct
PD690	Economics of Pipe Sizing and Pump Selection	12-13 Oct
PD027	Heating, Ventilating and Air-Conditioning Systems: Sizing and Design	12-14 Oct
PD146	Flow Induced Vibration with Applications to Failure Analysis	12-14 Oct
PD467	Project Management for Engineers & Technical Professionals	12-14 Oct
PD633	Overview of Nuclear Codes and Standards for Nuclear Power Plants ASME STANDARDS COURSE	12-14 Oct
PD674	International Business Ethics and Foreign Corrupt Practices Act	12-14 Oct
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PD720	Layout of Process Piping Systems NEW!	12-14 Oct
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PD691	Fluid Mechanics, Piping Design, Fluid Transients and Dynamics NEW!	12-15 Oct
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PD676	Strategic Thinking	14 Oct
PD102	How to Perform Elevator Inspections Using ASME A17.2 and ASME Safety Code A17.1 ASME STANDARDS COURSE	14-16 Oct
PD387	Understanding Chiller Performance, Operation and Economics	15 Oct
PD496	Preparing for the Project Management Professional Certification Exam	15-16 Oct
PD680	Understanding the Foreign Corrupt Practices Act	15-16 Oct
PD721	Optimization of Plant Layouts Utilizing 3D CAD/CAE Systems	15-16 Oct

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PD635 ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications 19-21 Oct
PD645 Code, Section IX: Welding, Brazing and Fusing Qualifications 19-21 Oct
PD720 Layout of Process Piping Systems NEW! 19-21 Oct
PD767 Pressure Relief Devices: Design, Sizing, Construction, Inspection and Maintenance ASME STANDARDS COURSE NEW! 19-21 Oct
PD616 API 579 /ASME FFS-1 Fitness-for-Service Evaluation 19-22 Oct
PD643 B31.3 Process Piping Code ASME STANDARDS COURSE 19-22 Oct
PD644 Advanced Design and Construction of Nuclear Facility Components Per BPV Code, Section III ASME STANDARDS COURSE 19-22 Oct
PD443 BPV Code, Section VIII, Division 1 Combo Course ASME STANDARDS COURSE (combines PD441 & PD442) **SAVE UP TO €800!** TOP SELLER 19-23 Oct
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PD721 Optimisation of Plant Layouts Utilising 3D CAD/CAE Systems NEW! 22-23 Oct

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OCTOBER 2015 – HOUSTON, TEXAS USA

PD539 Bolted Joints and Gasket Behavior 26-27 Oct
PD190 BPV Code, Section IX: Welding, Brazing and Fusing Qualifications ASME STANDARDS COURSE TOP SELLER 26-28 Oct
PD231 Shock and Vibration Analysis 26-28 Oct
PD268 Fracture Mechanics Approach to Life Predictions 26-28 Oct
PD370 B31.8 Gas Transmission & Distribution Piping Systems ASME STANDARDS COURSE 26-28 Oct
PD395 API 579-1/ASME FFS-1 Fitness-for-Service 26-28 Oct
PD442 BPV Code, Section VIII, Division 1: Design & Fabrication of Pressure Vessels ASME STANDARDS COURSE TOP SELLER 26-28 Oct
PD619 Risk and Reliability Strategies for Optimizing Performance 26-28 Oct
PD014 ASME B31.3 Process Piping Design ASME STANDARDS COURSE TOP SELLER 26-29 Oct
PD644 Advanced Design and Construction of Nuclear Facility Components Per BPV Code, Section III ASME STANDARDS COURSE 26-29 Oct
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PD577 Bolted Joint Assembly Principles Per PCC-1-2013 ASME STANDARDS COURSE 29-30 Oct
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NOVEMBER 2015 – DUBAI, UNITED ARAB EMIRATES

PD618 Root Cause Analysis Fundamentals 1-3 Nov
PD715 Principles of Welding and BPV Code, Section IX: Welding and Brazing Qualifications ASME STANDARDS COURSE 1-3 Nov
PD723 B31.4 and B31.8, Liquids and Gas Pipelines 1-3 Nov
PD726 API 579-1/ASME FFS-1 Fitness-For-Service Evaluation 1-3 Nov
PD642 ASME B31.1 Power Piping Code ASME STANDARDS COURSE 1-4 Nov
PD675 ASME NQA-1 Lead Auditor Training 1-4 Nov
PD725 BPV Code, Section VIII, Division 1: Design and Fabrication with Inspections, Repairs and Alterations of Pressure Vessels ASME STANDARDS COURSE 1-4 Nov

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PD107 Elevator Maintenance Evaluation 9-10 Nov
PD382 How to Predict Thermal-Hydraulic Loads on Pressure Vessels and Piping 9-10 Nov
PD077 Failure Prevention, Repair and Life Extension of Piping, Vessels and Tanks ASME STANDARDS COURSE 9-11 Nov
PD146 Flow Induced Vibration with Applications to Failure Analysis 9-11 Nov
PD389 Nondestructive Examination-Applying ASME Code Requirements (BPV Code, Section V) ASME STANDARDS COURSE 9-11 Nov
PD410 Detail Engineering of Piping Systems NEW! 9-11 Nov
PD506 Effective Management of Research & Development Teams and Organizations 9-11 Nov
PD513 TRIZ: The Theory of Inventive Problem Solving 9-11 Nov
PD515 Dimensioning and Tolerancing Principles for Gages and Fixtures 9-11 Nov
PD702 Process Safety and Risk Management for Mechanical Engineers NEW! 9-11 Nov
PD359 Practical Welding Technology 9-12 Nov
PD448 BPV Code, Section VIII, Division 2: Pressure Vessels ASME STANDARDS COURSE TOP SELLER 9-12 Nov
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PD665 BPV Code, Section I: Power Boilers ASME STANDARDS COURSE 9-13 Nov

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PD391 ASME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids ASME STANDARDS COURSE 16-17 Nov
PD449 Mechanical Tolerancing for Six Sigma 16-17 Nov
PD595 Developing a 10-Year Pump Inservice Testing Program 16-17 Nov
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PD618 Root Cause Analysis Fundamentals 16-18 Nov
PD683 Probabilistic Structural Analysis, Design and Reliability-Risk Assessment 16-18 Nov
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PD394 Seismic Design and Retrofit of Equipment and Piping 16-19 Nov
PD622 BPV Code: Plant Equipment Requirements ASME STANDARDS COURSE 16-19 Nov
PD632 Design in Codes, Standards and Regulations for Nuclear Power Plant Construction ASME STANDARDS COURSE 16-19 Nov
PD596 Developing a 10-Year Valve Inservice Testing Program 18-20 Nov
PD591 Developing Conflict Resolution Best Practices 19-20 Nov
PD583 Pressure Relief Devices: Design, Sizing, Construction, Inspection and Maintenance ASME STANDARDS COURSE 19-21 Nov

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PD539	Bolted Joints and Gasket Behavior	7-8 Dec
PD570	Geometric Dimensioning and Tolerancing Fundamentals 1 ASME STANDARDS COURSE	7-8 Dec
PD190	BPV Code, Section IX: Welding, Brazing and Fusing Qualifications ASME STANDARDS COURSE TOP SELLER	7-9 Dec
PD370	B31.8 Gas Transmission and Distribution Piping Systems ASME STANDARDS COURSE	7-9 Dec
PD395	API 579-1/ASME FFS-1 Fitness-for-Service	7-9 Dec
PD442	BPV Code, Section VIII, Division 1: Design and Fabrication of Pressure Vessels ASME STANDARDS COURSE TOP SELLER	7-9 Dec
PD615	BPV Code, Section III, Division 1: Class 1, 2 & 3 Piping Design ASME STANDARDS COURSE	7-9 Dec
PD720	Layout of Process Piping Systems NEW!	7-9 Dec
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PD577	Bolted Joint Assembly Principles Per PCC-1-2013 ASME STANDARDS COURSE	10-11 Dec
PD721	Optimization of Plant Layouts Utilizing 3D CAD/CAE Systems	10-11 Dec
PD584	Centrifugal Compressor Performance Analysis	10-12 Dec
PD457	B31.3 Process Piping Materials Fabrication, Examination and Testing ASME STANDARDS COURSE TOP SELLER	11 Dec

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PD389	Nondestructive Examination - Applying ASME Code Requirements (BPV Code, Section V)	14-16 Dec
PD442	BPV Code, Section VIII, Division 1: Design and Fabrication of Pressure Vessels ASME STANDARDS COURSE TOP SELLER	14-16 Dec
PD635	ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications ASME STANDARDS COURSE	14-16 Dec
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PD616	API 579 /ASME FFS-1 Fitness-for-Service Evaluation	14-17 Dec
PD642	ASME B31.1 Power Piping Code ASME STANDARDS COURSE	14-17 Dec
PD643	B31.3 Process Piping Code ASME STANDARDS COURSE	14-17 Dec
PD675	ASME NQA-1 Lead Auditor Training	14-17 Dec
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MC107	Design by Analysis Requirements in ASME Boiler & Pressure Vessel Code Section VIII, Division 2
MC112	Structural Materials and Design for Elevated to High Temperatures
MC113	Techniques and Methods used in API 579-1/ASME FFS-1 for Advanced Fitness-For-Service (FFS) Assessments
MC114	Repair Strategies and Considerations for Pressure Vessels and Piping
MC110	Bases and Application of Piping Flexibility Analysis to ASME B31 Codes
MC111	Piping Vibration Causes and Remedies - a Practical Approach
MC117	Piping Failures - Causes and Prevention
MC123	NEW! Fatigue Analysis Requirements in ASME BPV Code Section VIII, Division 2 – Alternative Rules
MC124	NEW! Inspection Planning Using Risk-Based Methods
MC125	NEW! Impact Testing and Toughness Requirements for Pressure Vessels; ASME Section VIII, Divisions 1 & 2
MC126	NEW! Design by Rule Requirements in ASME Boiler & Pressure Vessel Code Section VIII, Division 2
MC127	NEW! Use of Thermoplastic Piping Systems for Oil and Gas
MC128	NEW! Use of Multilayer Reinforced Thermoplastics and Thermoplastics for Oil and Gas
MC129	NEW! Managing Stress Corrosion Cracking in an Integrity Management Program for Pipelines
MC130	NEW! (B31.8S) Pipeline Risk Management
MC131	NEW! (B31.8S) Pipeline Integrity Issues, Mitigation, Prevention and Repair

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June 8–9 • Instructor: Scott Neumann

Geometric Tolerancing and Tolerance Stacks Applications (PD561)
June 10–11 • Instructor: Scott Neumann

B31.1 Power Piping Code (PD013)
June 8–12 • Instructors: Ronald W. Haupt, PE and Philip D. Flenner, PE

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July 13–15 • Instructor: Kamran Mokhtarian, PE

Inspections, Repairs and Alterations of Pressure Equipment (PD441)
July 16–17 • Instructor: Kamran Mokhtarian, PE

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July 13–16 • Instructor: Ronald W. Haupt, PE

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Image: Future Facilities

THERMAL SIMULATION TOOL

FUTURE FACILITIES, LONDON.

Release 9 of 6SigmaET integrates a new computational fluid dynamics solver that can speed thermal simulation, and introduces a number of enhancements to the tool's functionality and user interface. According to the developer, an operator can load a 3-D CAD model for analysis as is, with minimal simplification or translation. The object-based gridding in the software automatically recognizes the CAD model and prepares it for the simulation. Results can be post-processed directly onto the CAD objects.

ACOUSTIC SIMULATION

CD-ADAPCO, MELVILLE, N.Y.

The wave6 product line analyzes flow-induced noise and vibration problems. It is designed to complement and extend the functionality of the company's flagship simulation tool, STAR-CCM+. The new software includes automated work flows intended to make advanced vibro-acoustic and aero-vibro-acoustic analysis methods more readily accessible to users.

REVERSE ENGINEERING

DELCAM LTD., BIRMINGHAM, U.K.

By offering a combination of solid, surface, and direct modeling, together with reverse engineering, PowerSHAPE Pro provides a range of design techniques in a single CAD program. Having many different technologies in the same package reduces the need to transfer data between different programs and so streamlines product development that requires reverse engineering and CAD functionality. PowerSHAPE Pro can connect directly to most scanning hardware to capture and display scan data in real time.

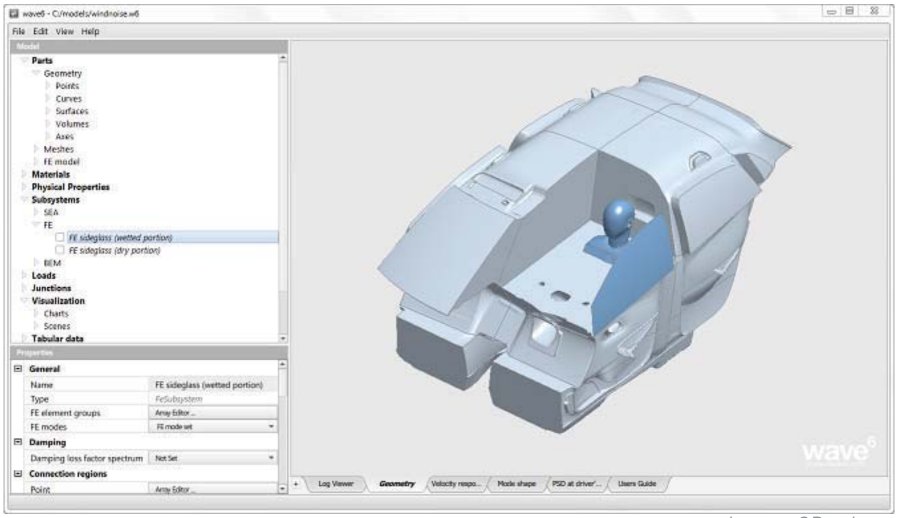

Image: CD-adapco

SIMULATION SOFTWARE

ANSYS, PITTSBURGH.

The newly released ANSYS 16.0 includes a variety of new functions. According to the developer, advances have been made across the software's entire portfolio of digital prototyping, including structures, fluids, electronics, and systems engineering. Another new feature is the ability to create 3-D components and integrate them into larger electronic assemblies.

MATERIAL MANAGEMENT

SIEMENS AG, MUNICH.

Teamcenter contains new integrated materials management software developed by Siemens AG in partnership with thinkstep of Echterdingen, Germany. The software lets manufacturers connect design, engineering, analysis, and manufacturing to a single source of material information. Siemens says it can reduce the errors caused by inaccurate material data. It will also assist in the re-use of market tested materials for new products.

VIRTUAL PROTOYPING

ESI GROUP, PARIS.

Virtual Seat Solution lets OEMs and vehicle seat suppliers design, test, improve, and pre-certify their designs virtually, without the need for physical prototypes. The software not only covers trim manufacturing, postural, and static and dynamic comfort, but also enables the assessment of thermal comfort and whiplash testing. In addition, Virtual Seat Solution ensures accurate prediction of the seat performance. Users can evaluate performance, precisely predicting the interaction between seat and passengers.

INTEGRATOR FLOW

MENTOR GRAPHICS CORP., WARREN, N.J.

The Package Integrator solution automates planning, assembly, and optimization of today's complex multi-die packages. It incorporates a virtual die model concept for true integrated circuit-to-package co-optimization. In support of early marketing-level studies for a proposed new device, users can now plan, assemble, and optimize complex systems with minimal source data. The new Package Integrator flow allows design teams to realize faster and more efficient physical path finding and seamless tool integration for rapid prototyping, right to the production flow. This solution ensures that ICs, packages, and printed circuit boards are optimized with each other to reduce package substrate and PCB costs by efficient layer reduction, optimized interconnect paths, and streamlined/automated control of the design process.

EMBEDDED SYSTEMS

ALTAIR ENGINEERING, TROY, MICH.

VisSim 9.0 increases engineering productivity and expands its support of the Texas Instruments C2000 control products. Speed improvements have been made to large plots and overall simulation, as well as to large diagrams with many conditional subsystems. Multi-scaled plots, polar plots, and a block and diagram finder have been added. New embedded features include an execution ordering block, a CRC16 block, and TI MotorWare InstaSPIN FAST and SpinTAC blocks for programming sensorless field-oriented control motors.

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.

CONDUCTIVITY CONTROLLERS

OMEGA ENGINEERING, STAMFORD, CONN.

OMEGA's new CDTX-111/CDTX-112 series of conductivity controllers are panel instruments for online monitoring of industrial process conductivity. The CE compliant products include such features as linearized data, automatic temperature compensation, no error due to cable length changes, and maintenance-free cells. The controllers can be used in the automotive, chemical, and water industries, for instance, for measurement and control of conductivity in water, electronics, chemical, and manufacturing processes.

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LARGE-SCALE 3-D PRINTING

STRATASYS LTD., EDEN PRAIRIE, MINN.

The industrial scale Objet1000 Plus 3-D production system offers large print size and accelerated speeds for demanding manufacturing applications including aerospace, automotive, medical, and consumer products as well as for service bureaus and universities. The Objet1000 Plus can mix materials and part sizes while maintaining ultra fine precision. Its extra large build envelope is traversed with a new optimized print block movement.

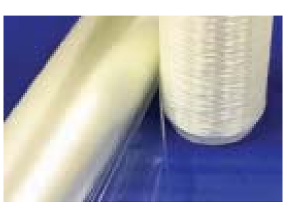
SERIES RELAYS

AUTOMATION DIRECT, CUMMING, GA.

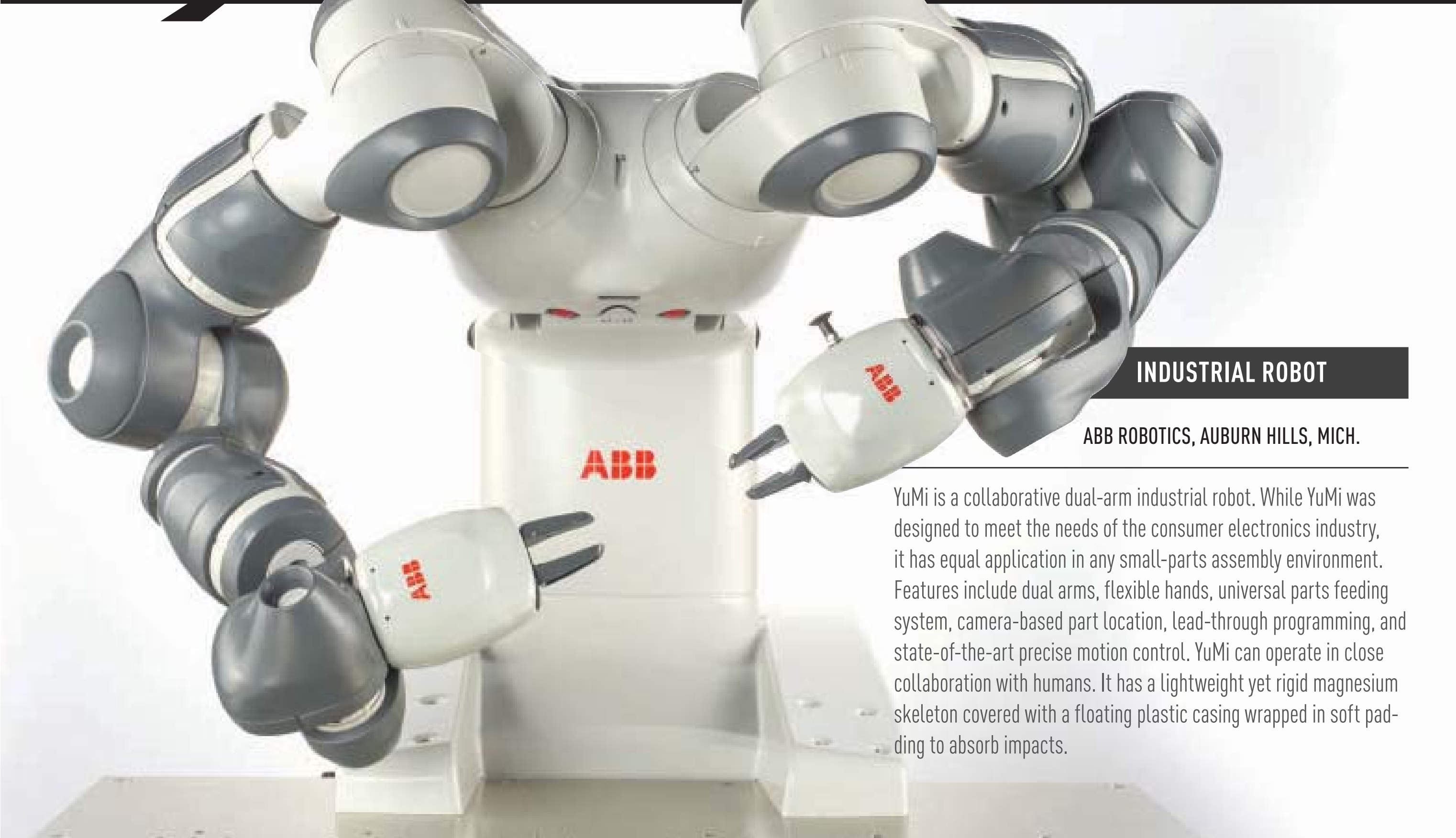
The 750R series relays are 10-amp general purpose relays designed for a wide range of applications, from power to sequence controls in various factory machines and control panels. They are good for electrical control panels requiring stable and reliable relays. The 750R series features an octal base design, silver alloy with gold flashed contacts, and 1,500 V rms open contact dielectric strength. These electromechanical relays provide reliability and long life, as well as high vibration and shock resistance.

POLYAMIDE FOR MEDICAL DEVICES

FOSTER POLYMER DISTRIBUTION, PUTNAM, CONN.



MX-Nylon is a high-strength material to replace metals. It has a flexural modulus 50 percent greater than traditional polyamide 6/6 and 15 percent greater than polyetheretherketone (PEEK). It is an economical option for components that must be radiolucent and high strength. MX-Nylon also offers good gas barrier properties against oxygen and carbon dioxide compared to all commercially available polyamides, as well as ethylene-vinyl alcohol (EVOH) copolymers, acrylonitrile copolymers, and polyvinylidene chloride (PVDC) copolymers.



INDUSTRIAL ROBOT

ABB ROBOTICS, AUBURN HILLS, MICH.

YuMi is a collaborative dual-arm industrial robot. While YuMi was designed to meet the needs of the consumer electronics industry, it has equal application in any small-parts assembly environment. Features include dual arms, flexible hands, universal parts feeding system, camera-based part location, lead-through programming, and state-of-the-art precise motion control. YuMi can operate in close collaboration with humans. It has a lightweight yet rigid magnesium skeleton covered with a floating plastic casing wrapped in soft padding to absorb impacts.

PRESSURE TRANSMITTERS

GEMS SENSORS & CONTROLS, PLAINVILLE, CONN.

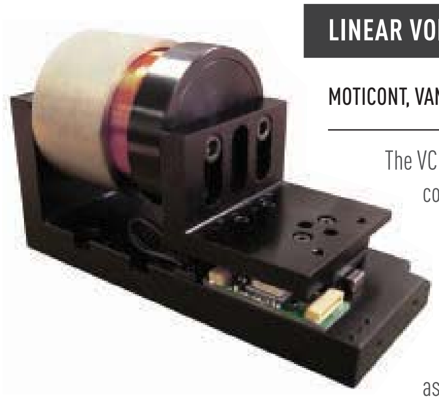
The new Model 3800 Series pressure transmitter is available in seven ranges from 0 to 10,000 psi (0 to 689 bar), with choice of loop powered (4-20 mA) or low power (1-5 V dc) output. They offer a ±0.25 percent URL (BFSL) linearity, hysteresis, and repeatability specification, with less than 5 millisecond response times. Depending upon selected range, burst pressures extend from 4x up to 40x FSPR, with 2x or 3x overpressures.

QUICK PITCH ADJUSTMENT

AMACOIL INC., ASTON, PA.

The pitch control lever permits manually setting and changing linear pitch independently of the drive motor speed or other controls. This means that motors and devices in a machine may continue operating at production speed without interruption while the drive unit's linear pitch is changed or adjusted to meet application requirements. Each of 17 models of Uhing rolling ring drives has a different maximum linear pitch. The largest drive has a pitch of 76 mm (3.0 in.).

LINEAR VOICE COIL STAGES



MOTICONT, VAN NUYS, CALIF.

The VCDS-051-089-01 series linear motion voice coil stages feature a voice coil motor, a ball bearing linear slide, home switch, and an integral optical quadrature encoder with differential outputs. Measuring 13.5 in (342.9 mm) long x 4 in. (101.6 mm) wide x 3.755 in. (95.4 mm) high, the VCDS-051-089-01 series linear motion voice coil stages are found in manufacturing, medical, aerospace/defense, and inspection applications such as measuring, optical and electrical inspection, assembly, packaging, semiconductor handling, scanning, and sampling.

TEMPERATURE TRANSMITTERS

MOORE INDUSTRIES, NORTH HILLS, CALIF.

The THZ3 and TDZ3 transmitters are both HART and DTM (device type manager) programmable. They can be programmed and interrogated from anywhere at any time on a 4-20 mA loop. This can be done with a standard HART handheld communicator, a HART-compatible host, or with any field device tool compliant host or program such as PACTware utilizing DTM. The PACTware software can be downloaded directly from the Moore Industries website and can be used with any manufacturer's DTM.

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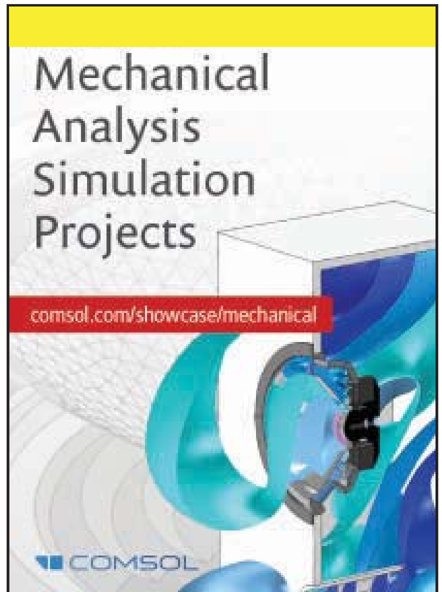

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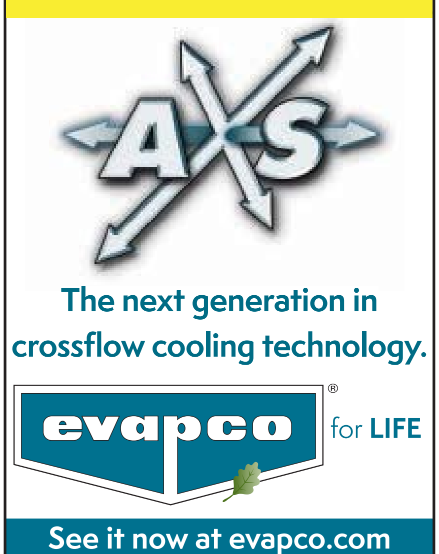

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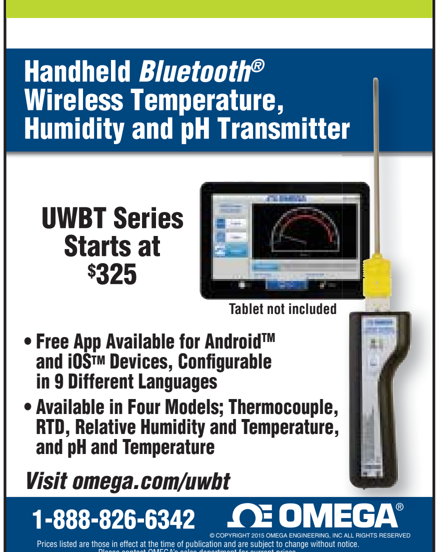

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CONSULTING

DASGUPTA WINS MARYLAND SCHOLARSHIP AWARD

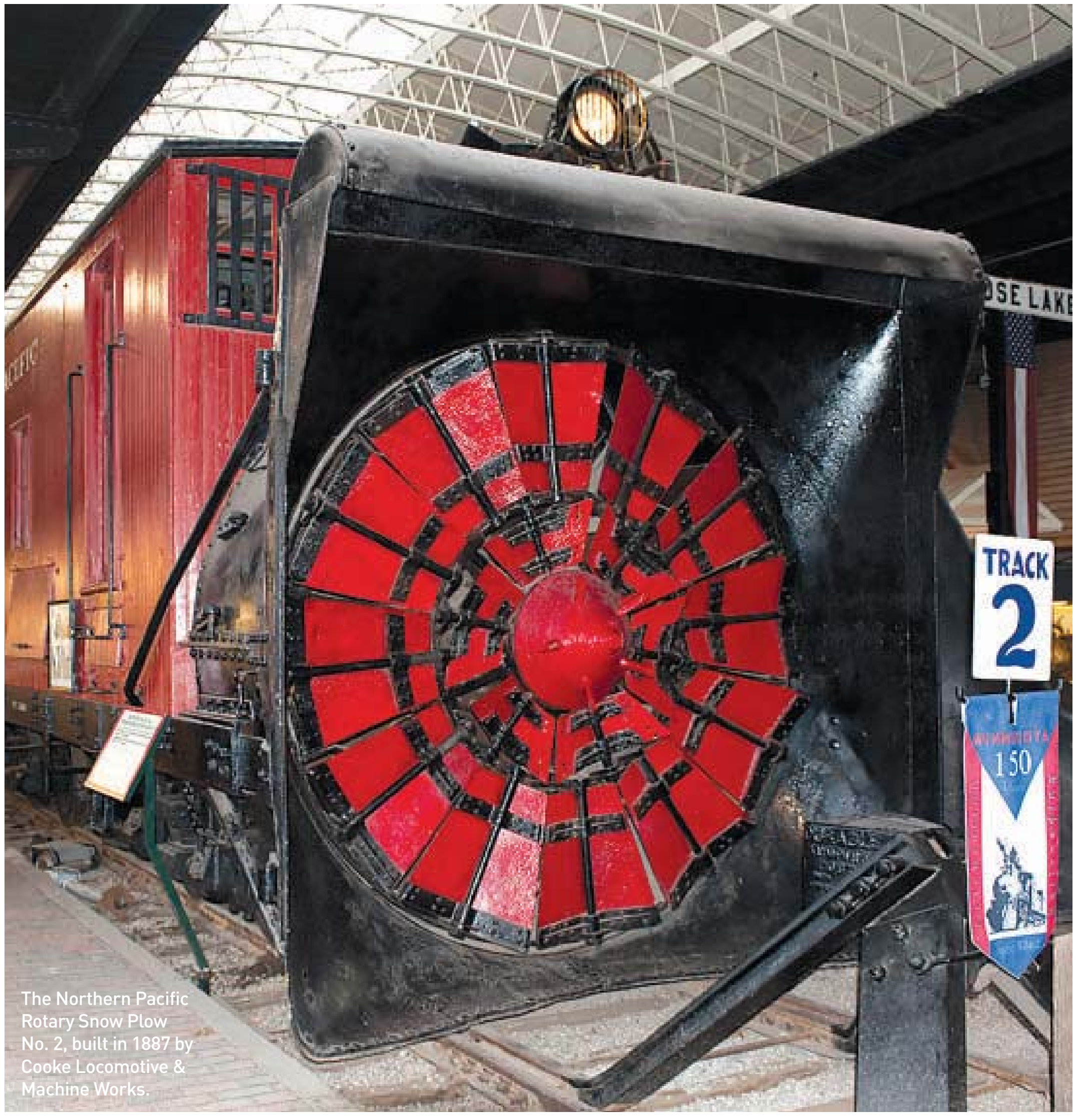
ASME Fellow **Abhijit Dasgupta** has been awarded a 2015 Regents' Faculty Award for Excellence in Scholarship by the University System of Maryland. Dasgupta, the Department of Mechanical Engineering Jeong H. Kim Professor at the University of Maryland in College Park, has conducted research on physics of failure approaches for developing reliable, complex multi-functional systems that perform electronic, photonic, and mechanical functions. He is also a researcher for the University of Maryland's Center for Advanced Life Cycle Engineering.

Dasgupta is the former secretary and treasurer of the ASME Electronic and Photonic Packaging Division, and former associate editor of the ASME *Journal of Electronic Packaging*.

The USM Regents' Faculty Awards are the highest honor presented by the Board of Regents to exemplary faculty members.

ERTURK HONORED FOR EARLY ACHIEVEMENT

Alper Erturk, assistant professor of acoustics and dynamics at Georgia Institute of Technology in Atlanta, has been named the 2015 recipient of the ASME Gary Anderson Early Achievement Award. The prize is awarded by the ASME Aerospace Division to a young researcher in his or her ascendancy whose work has already had an impact in his or her field within adaptive structures and material systems. Erturk, who received his doctorate in engineering mechanics from Virginia Tech in 2009, joined Georgia Tech as an assistant professor in May 2011 after working as a research scientist at Virginia Tech's Center for Intelligent Material Systems and Structures. His postdoctoral research interests included theory and experiments of piezoelastic structures for applications ranging from aeroelastic energy harvesting to nonlinear vibrations of electroelastic systems.



The Northern Pacific Rotary Snow Plow No. 2, built in 1887 by Cooke Locomotive & Machine Works.

WIENS, TOMBOULIAN, AND FANG

For the first time in the history of ASME's Federal Government Fellowship Program, three female ASME members are serving simultaneously as ASME Federal Government Fellows.

Gloria Wiens, associate professor of mechanical and aerospace engineering at the University of Florida, and **Briana Tomboulian**, who recently earned a Ph.D. from the University of Massachusetts, Amherst, are serving in Washington, D.C.

Maureen Fang, a former Pratt & Whitney mechanical engineer and current Ph.D. candidate in mechanical engineering technology at Purdue University in West Lafayette, Ind., is the Society's inaugural Advanced Manufacturing Fellow at the Youngstown, Ohio, headquarters of the America Makes innovation center.

The ASME Federal Government Fellowship Program enables ASME members to devote a year working in government in order to provide technical advice to policy makers and key federal agencies. Traditionally, ASME Federal Fellows have served in either the executive or legislative branch.

ASME began the program in 1973.

Wiens has spent two one-year terms as a Swanson Fellow, serving as the assistant director for research partnerships at the Advanced Manufacturing National Program Office.

ROTARY SNOW PLOW NAMED ASME LANDMARK

As railroads knitted together North America in the 19th century, they ran into an insidious challenge: deep snow in high mountain passes and the northern Great Plains could render railways impassible.

The Northern Pacific Rotary Snow Plow No. 2, built in 1887 by Cooke Locomotive & Machine Works of Paterson, N.J., was instrumental in keeping freight and passenger rail systems in operation, even in the harshest of winter conditions. Featuring a rotary blade that removed snow in the same fashion as the typical home snow blower today, the snow plow was named a Historic Mechanical Engineering Landmark in an April ceremony at the Lake Superior Railroad Museum in Duluth.

The Northern Pacific No. 2, now retired, is the oldest rotary snow plow in existence. It is on permanent display at the museum.

In building the Rotary Snow Plow No. 2, Cooke Locomotive & Machine Works advanced earlier designs to develop a novel rotational wheel mechanism that could revolve in both directions to throw snow right and left. The unit was pushed by three or four steam locomotives, moving at a speed of 4 to 6 miles per hour.

“Rotary plows proved much more effective against heavy snowfalls than wedge plows and manual labor,” reads a bronze plaque created by ASME for the Lake Superior Railroad Museum. “It used a bi-directional rotating wheel with blades that cut into snow and passed it into an impeller.”

The plow was originally pressed into service to clear deep snow drifts in the Cascade Mountains region; it was later sent east to the plow railroads in Minnesota and North Dakota, where it worked until the World War II years.

Herman Viegas, an ASME Fellow and member of ASME’s History and Heritage Committee, was joined by officials of the Lake Superior Railroad Museum at the ceremony.

For more information on the ASME History and Heritage Historic Mechanical Engineering Landmarks Program, visit www.asme.org/about-asme/engineering-history/landmarks. ME

ARE FEDERAL FELLOWS

Tomboulian began her one-year term as an ASME Congressional Engineering Fellow in January. She is serving in the office of Sen. Ed Markey (D-Mass.), providing technical expertise on energy and environmental issues, composing memos and remarks for the senator, and preparing him for congressional hearings and committee meetings.

Fang is working full-time during her fellowship at America Makes, while continuing research for her Ph.D. dissertation at night and on the weekends.

“I finished most of my responsibilities at Purdue and now have the opportunity to perform my research off campus while doing this fellowship,” Fang said. “I come from industry, so being able to work with a non-profit organization like ASME and a public-private partnership like America Makes is very exciting. I’m grateful to be here.”

The ASME Federal Government Fellowship Program is made possible through the financial support of the ASME Foundation. To learn more about ASME Federal Government Fellowship Program, visit www.asme.org/about-asme/get-involved/advocacy-government-relations/federal-fellows-program.

An article by recent Federal Fellow Bharat Bhushan appears on PAGE TK of this issue. ME

METZ TO LEAD NAVY PROGRAMS AT AMERICAN SYSTEMS

ASME member **Stephen Metz**, a 31-year U.S. Navy veteran, has been named vice president and executive director of Navy programs at American Systems, a leading provider of government information technology and engineering solutions. Metz will manage the company’s existing business units, which focus on various U.S. Department of the Navy markets, including the Naval Undersea Warfare Center, Naval Surface Warfare Center, Naval Sea Systems Command, Space and Warfare Systems Command, and Surface Fleet Commands. As DDG project officer, Metz managed the reconstruction and return of the USS *Cole* to the operational fleet following the terrorist attack on the vessel in 2000. Metz earned a bachelor’s degree in marine engineering from the U.S. Naval Academy, and master’s degrees from the U.S. Naval Postgraduate School and the Industrial College of the Armed Forces.

WEBINAR ON WOMEN IN GLOBAL DEVELOPMENT IN E4C ARCHIVE

Careers in engineering for global development is the focus of a multi-part webinar series offered by Engineering for Change. The first segment took place on April 29 and featured women and their roles as leaders in global development. The speakers included **Heather Fleming**, co-founder and CEO of Catapult Design; **Diana Keesiga**, program engineer at Water for People; and **Jordan Schermerhorn**, co-founder of Dunia Health.

A recording of the webinar can be streamed via the E4C webinar archive, www.engineeringfor-change-webinars.org/.

ASME REPRESENTATIVES DISCUSS STEM ON BLOG TALK RADIO

Thomas Perry and **Aisha Lawrey** of ASME’s engineering education program joined **Teodora Shuman**, mechanical engineering department chair at the University of Seattle, and **James Brown**, executive director of the STEM Education Coalition, to discuss the topic “Setting the K-12 Course for Women in Engineering” on Blog Talk Radio. The program was hosted by **Larry Jacobs**, president of Education Talk Radio. A recording of the discussion is available at www.blogtalkradio.com/edutalk/2015/03/20/setting-the-k-12-course-for-women-in-engineering.

BAMBOO ON WHEELS

A VIETNAMESE ENGINEER MAKES USE OF AN ABUNDANT LOCAL MATERIAL.

Bamboo might seem little more than an exotic novelty for many engineers in Western countries, but in East Asia, it is an important part of everyday life. It's not unusual to see bamboo being used for everything from furniture to construction scaffolding.

Pham Minh Tri, a Vietnamese engineer, grew up surrounded by bamboo. But it wasn't until he traveled to Germany for graduate studies in automotive engineering that he saw a presentation about bamboo bicycles that would change his life.

"There's a lot of bamboo in Vietnam, but people don't realize the potential," Pham said. "I always knew I wanted to return to Vietnam after my education and start a business that would be a real contribution for the next generation."

And so, Pham quietly began researching his idea of producing high-quality bamboo bicycles. "I discovered that the RWTH Aachen University had developed a chart comparing the tensile strength of bamboo with steel," Pham said. (The information is available online at tinyurl.com/m3emwyo.)

Pham returned to Vietnam in 2012 to design and build his first bike frame. It weighed about the same as a comparable steel or aluminum frame—just over two kilograms.

Other bike manufacturers, even in the U.S., are using bamboo, which they say is comparable to materials like carbon fiber and titanium. High-performance bamboo bicycles can cost $2,000 and upwards. Riders claim better handling and crash tolerance than they get with metal frames.

Pham's goal in establishing his company, Viet Bamboo Bike, was to design and engineer his bikes from "the bottom up," to create a high-quality, diverse line at lower prices.

Pham first needed a reliable source of high-quality bamboo. "Bikes require about 4.5 millimeters of thickness, which compares to 1.5 millimeters for steel," he said. "I found a furniture exporter who can supply me with carbonized bamboo."

One of the biggest challenges was deciding on the connections for the frame. "The joints or lugs need to be strong enough to handle the stress of the weight—which concentrates on the bottom of the frame—without being too thick." After numerous experiments, and finding a higher quality epoxy than was available in Vietnam, Pham decided on two different options: carbon fiber, or hemp with fiberglass.

According to Pham, controlling the direction of the hemp while wrapping was difficult and joints had to be sanded to shape. "If the joint is too thin, or too thick, it will impact on the quality," Pham said. "So I decided to use the fiberglass layer inside to ensure reinforcement."

Carbon fiber, he noted, is thinner, "but sanding needs to be done very carefully." It's also toxic, so workers must wear safety clothes.

Pham built and designed his own testing machine for the frames, and has applied for an ISO quality certificate.

Viet Bamboo offers three frames for uses as diverse as city cycling or mountain trekking. His goal is to reduce manufacturing time from 40 hours to 20. Pham recently hired three employees to help build the bikes, so he could focus more on design and marketing.

Pham expects the bikes to retail for about $1,500 if sold through export distributors. He is considering a Kickstarter campaign for direct-to-consumer sales at $750 a bike. Viet Bamboo is currently selling frames to Ride Bamboo in Germany, and Pham said he is in talks with distributors in Switzerland, the U.K., and the U.S. ME

LARRY LEVENTHAL is a writer currently based in Southeast Asia.

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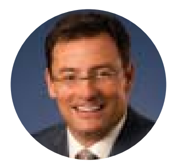

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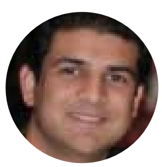

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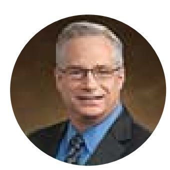

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