2016–2017 ANNUAL REPORT

COLLEGE OF ENGINEERING
MECHANICAL ENGINEERING
UNIVERSITY OF MICHIGAN

Contents

Mechanical Engineering Annual Report 2016–2017

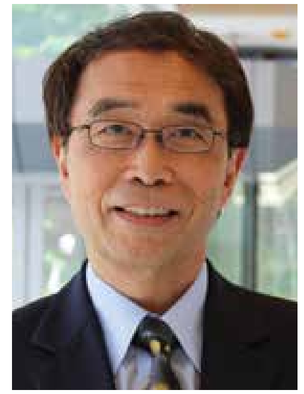
ON THE COVER: Rubik's Cube spinning (See page 36 for details)

INSIDE SPREAD: Newly installed outdoor sculpture (See page 13 for details)

Photos: Joseph Xu, Michigan Engineering

Message from the Chair

Our top-ranked program is shaping a generation of engineers who are passionate about making a contribution and eager to take a collaborative, multidisciplinary approach to tackle problems impacting society.



Thank you for your interest in the University of Michigan (U-M) Mechanical Engineering (ME) department. The year 2018 marks our 150th anniversary and, as we head into our sesquicentennial year, we have much to celebrate and share.

Our research continues to drive advances far beyond traditional mechanical engineering disciplines. Our top-ranked program is shaping a generation of engineers who are passionate about making a contribution and eager to take a collaborative, multidisciplinary approach to tackle problems impacting society.

Our faculty again have been recognized for their research and professional leadership. This year, Ellen Arruda, the Maria Comninou Collegiate Professor of Mechanical Engineering, and Noboru Kikuchi, the Roger L. McCarthy Professor Emeritus of Mechanical Engineering, were elected to the prestigious National Academy of Engineering. Many other faculty members have been honored with a spate of competitive awards, including some of the highest honors in professional societies, such as ASME, IEEE, SAE and SME. We welcome three new assistant professors, Rohini Bala Chandran, Elliott Rouse and Alex Shorter. You'll read about many faculty research advances in the following pages, advances that span mechanics, dynamics, thermal/fluids and scientific computing to energy, bio-systems, nanotechnology, transportation, and manufacturing.

On the facilities front, following the $50 million major renovation of the GG Brown building, we recently completed another construction project: the interior renovation of the Lay Automotive Laboratory building. The transformed space includes updated corridors and staircases, improved lighting and displays, new and remodeled lounges, conference rooms, restrooms and a lactation room. Flooring and walls have been refinished, and faculty and student offices have been remodeled and upgraded. The new space is already providing a welcoming, productive environment both for occupants and the Auto Lab's many visitors.

Nine of our students—eight graduate and one undergraduate—have earned prestigious NSF Graduate Research Fellowships this year, making U-M ME among a few ME programs nationwide with the highest number of 2017 recipients.

Our rigorous Design and Manufacturing undergraduate course spine (ME250, 350, 450) has significantly inspired our students' creativity, and provided them a strong education in engineering and other skills. To underscore the need for collaboration to solve almost any problem, through ME450 a team of creative ME students have conceived of, designed and built a massive Rubik's cube as a work of functional art for our campus. The 1,500-pound cube is now installed—and frequently used—on the second floor of GG Brown. Our ME students also gain invaluable engineering experience globally through many international programs. Student teams have put the breadth and depth of their engineering education to work in their competitive pursuits, with outstanding results, as you'll read shortly.

As always, our alumni—over 16,000 living members—continue to support and inspire us through their professional accomplishments as well as their contributions of time, resources and experience.

We hope you'll join us at one of our sesquicentennial events in 2018. Please visit our website for details.

Wishing you a productive year of discovery,

Kon-Well Wang
Tim Manganello/BorgWarner Department Chair and Stephen P. Timoshenko Collegiate Professor

Faculty Profile

10 NAE Members*

79 Society Fellows

4 NSF PECASE or PFF Awards

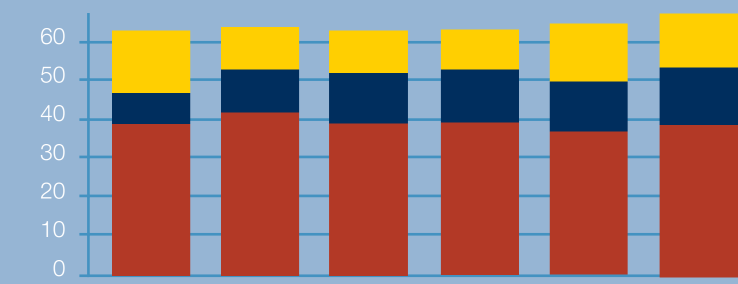
37 NSF CAREER or PYI Awards

4 Current Journal Chief Editors

73 Current Journal Editorial Board or Assoc. Editor Appts.

*Including Emeritus Faculty

Faculty Trends: Tenured and Tenure-Track

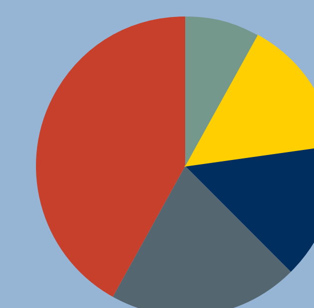


	FA12	FA13	FA14	FA15	FA16	FA17
Assistant	16	11	11	11	15	14
Associate	8	11	13	14	13	15
Professor	39	42	39	39	37	39
Total	63	64	63	64	65	68

Annual Research Expenditures

TOTAL RESEARCH EXPENDITURES
$35,216,527

2016–17

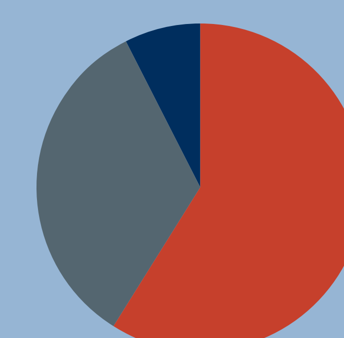


NIH $2,923,860
NSF $5,148,384
DoE $5,198,455
DoD $7,211,332
All Other $14,734,496

Degrees Conferred

2015–16

BSE 299
MSE 172
PhD 37



ME Professor Ellen Arruda and Professor Emeritus Noboru Kikuchi
Elected to the National Academy of Engineering

Ellen Arruda and Noboru Kikuchi, University of Michigan Mechanical Engineering professor and professor emeritus noted for leadership in their fields, have been elected to the National Academy of Engineering (NAE). Election to the NAE is among the highest professional distinctions accorded to an engineer.

Arruda, Maria Comninou Collegiate Professor of Mechanical Engineering at the University of Michigan, is being cited for her “pioneering research in polymer and tissue mechanics and their application in innovative commercial products.” Arruda received both her bachelor’s and master’s degrees from Pennsylvania State University and her PhD from Massachusetts Institute of Technology. She also holds joint appointments in Biomedical Engineering and in Macromolecular Science and Engineering at U-M. Recognized as a trailblazer in her field, Arruda’s groundbreaking research and teaching has secured her position as a world leader in the areas of theoretical and experimental mechanics of macromolecular materials, including polymers, elastomers, composites, soft tissues and proteins, and in tissue engineering of soft tissues and tissue interfaces. Her work has made a tremendous impact on improving human health and life, such as advancing technologies for the repair of the anterior cruciate ligament and development of a shock-absorbing helmet to prevent brain injury. Arruda is president and fellow of the American Academy of Mechanics, a fellow of ASME and fellow and former president of the Society of Engineering Science.

Kikuchi, Roger L. McCarthy Professor Emeritus of Mechanical Engineering at the University of Michigan, has been touted for his “contributions to theory and methods of computer-aided engineering and leadership in their applications in the automotive industry worldwide.” Kikuchi received his bachelor’s degree from the Tokyo Institute of Technology and his master’s and PhD degrees from the University of Texas at Austin. He served on U-M’s Mechanical Engineering faculty from 1980 to 2015 and is currently the President and Chief Operating Officer for Toyota Central R&D Labs Inc. in Aichi, Japan. He is a world-renowned scholar in adaptive finite element methods including automatic mesh generation and remeshing schemes for nonlinear problems. His groundbreaking research achievements include the development of micromechanical models for unilateral contact friction of metal and sheet-metal forming processes, topology optimization for material microstructures and homogenization method in mechanics of composites. He developed the image-based computer-aided engineering (CAE) methodology and the First Order Analysis Method for CAE of automotive body structures. His publication record is unparalleled, with more than 10,000 citations.

ME Faculty Honored with Coveted Awards

The research and educational efforts conducted by U-M ME faculty are far-ranging in scope, and the advances and contributions made by many of our faculty are widely and frequently recognized by professional societies by conferring prestigious awards. Over the past year (2016–17), ME faculty have been honored with highly coveted awards for the depth, breadth and forward thinking of their work. Several recent honors are highlighted below (more awards listed on page 45).

JYOTI MAZUMDER

ASME/SME Eugene Merchant Manufacturing Medal: The M. Eugene Merchant Manufacturing Medal of ASME/SME is awarded to an individual who has had significant influence and responsibility for improving the productivity and efficiency (either by research or by implementation of research) of the manufacturing operation. In addition to his appointment in ME, Mazumder also is a professor of Materials Science and Engineering, as well as the director of the Center for Laser-Aided Intelligent Manufacturing and the director of the NSF.

JIM BARBER

ASME Mayo D. Hersey Award: The Mayo D. Hersey Award is bestowed on an individual in recognition of distinguished and continued contributions over a substantial period of time to the advancement of the science and engineering of tribology. This award was established in 1965 by the joint bequest of the ASME Lubrication Division (now Tribology Division) and the ASME Research Committee on Lubrication (now Research Committee on Tribology) to recognize the immense leadership in lubrication science and engineering of Mayo D. Hersey. Barber’s pioneering work exemplified significant original research in one or more of the many scientific disciplines related to lubrication, from excellence and creativity in lubrication engineering practice, or from sustained and forthright efforts and dissemination of information on the theory and practice of lubrication.

KON-WELL WANG

ASME J.P. Den Hartog Award and ASME Adaptive Structures & Material Systems Best Paper Award: The ASME J.P. Den Hartog Award is one of the most prestigious honors in the field of dynamics and vibration. This award recognizes lifetime contributions to the teaching and practice of vibration engineering. Given in odd-numbered years, the award was established in 1987 and operated as a division award until 2010 when it was elevated to a Society award. Wang is recognized for “his lifelong achievements in structural dynamics and vibration; and for outstanding work that has cross-linked multiple fields to synthesize novel adaptive structures with piezoelectric circuitry network, bistable and metastable elements and biologically inspired or nanoscale composites for vibration and control enhancement.” Wang also was awarded an ASME Adaptive Structures & Material Systems Best Paper Award.

ME Faculty Awards con't.

JACK HU

SME Gold Medal: The SME Gold Medal recognizes outstanding service to the manufacturing engineering profession in technical communications through published literature, technical writings or lectures. Hu is a 2017 SME Gold Medal awardee in recognition of his intellectual leadership in inventing novel algorithms and practical methodologies for multistation assembly systems and their impact implementation in industry, as well as his influential service to the government and manufacturing profession. He serves as the U-M's Vice President for Research and has overall responsibility for nurturing the excellence and integrity of research across the U-M campuses in Ann Arbor, Dearborn and Flint.

JWO PAN

SAE Medal of Honor: Established in 1986, the SAE Medal of Honor is presented annually and is SAE International's most prestigious award. This award recognizes an SAE International member for his or her unique and significant contributions to SAE that strengthen or add to SAE's ability to further its purpose. Pan has been active in SAE International by organizing sessions, recruiting new session organizers, founding committee activities and improving conference and technical paper qualities. His efforts have enhanced the importance, visibility and success of SAE International by improving the quality of its most important products: conference and technical papers. Pan has been educating and nurturing engineers and future leaders serving the mobility industry through his teaching at the U-M and his service in SAE International.

ANNA STEFANOPOULOU AND JASON SIEGEL

IEEE Control Systems Technology Award: The IEEE Control Systems Society (CSS) selected Professor Anna Stefanopoulou and Assistant Research Scientist Jason Siegel to receive the 2016 Control Systems Technology Award "for the development of an advanced battery management system accounting for electro-thermo-mechanical phenomena." The Control Systems Technology Award is bestowed "to a team or individual for an outstanding control systems technology contribution in either design and implementation or project management."

YORAM KOREN

SME Yoram Koren Outstanding Young Manufacturing Engineer Award (Namesake): Professor Emeritus Yoram Koren has been selected by both the SME Board of Directors and the International Awards & Recognition Committee as the namesake of the 2017 SME Outstanding Young Manufacturing Engineer Award. Establishing a namesake for this award honors an individual for his or her lifelong contributions to manufacturing, commitment to serving as a role model and motivator for young engineers and long-term active involvement in SME.

NEIL DASGUPTA

AVS Paul Holloway Young Investigator Award and Yoram Koren SME Outstanding Young Manufacturing Award: Assistant Professor Neil Dasgupta was selected as a recipient of the American Vacuum Society (AVS) 2016 Paul Holloway Young Investigator Award for his outstanding theoretical and experimental work in an area important to the Thin Film Division of AVS. Dasgupta also was a recipient of the 2017 Yoram Koren SME Outstanding Young Manufacturing Award.

CHINEDUM OKWUDIRE

SAE Ralph R. Teetor Educational Award and SME Outstanding Young Manufacturing Engineer Award: The SAE Ralph R. Teetor Award is given in recognition of outstanding contributions to SAE's engineering education initiatives. It seeks to stimulate contacts between younger engineering educators and practicing engineers in industry and government. Okwudire also was awarded the 2016 SME Outstanding Young Manufacturing Engineer Award.

ME Faculty Awards con't.

GALIP ULSOY

ASME Rudolf Kalman Best Paper Award: This award is given annually by the Dynamic Systems and Control Division (DSCD) of ASME to the authors of the best paper published in the ASME *Journal of Dynamic Systems Measurement and Control* during the preceding year. Ulsoy has been selected to receive the 2016 ASME Rudolf Kalman Best Paper Award for his paper entitled "Time-Delayed Control of SISO Systems for Improved Stability Margins," ASME *Journal of Dynamic Systems, Measurement and Control*.

HUEI PENG

ASME Michael J. Rabins Leadership Award: Professor Huei Peng received the ASME Dynamic Systems and Control Division Michael J. Rabins Leadership Award for demonstrating sustained outstanding leadership contributions to the DSCD and ASME, and to the fields of interest to the DSCD. This award is given biennially by the Dynamic Systems and Control Division of ASME to a DSCD member.

DAWN TILBURY

Engineering Society of Detroit ESD Gold Award: Professor Dawn Tilbury was selected to receive this year's Engineering Society of Detroit (ESD) Gold Award. Now in its 45th year, the Gold Award honors engineering leaders for outstanding technical contributions and dedication to the profession. Tilbury was nominated by the Society of Women Engineers-Detroit Professional Section.

Faculty Professorships

Pictured standing from left, Randy Visintainer, Director, Autonomous Vehicles & Controls – R&AE, Ford, Robert J. Vlasic Dean of U-M Engineering, Alec Gallimore, and Tim Manganello/ BorgWarner Department Chair and Stephen P. Timoshenko Collegiate Professor, Kon-Well Wang. Front seated, William Clay Ford Professor Anna Stefanopoulou

Anna Stefanopoulou

William Clay Ford Professorship

The William Clay Ford Professorship was created in 1989 with a generous gift from Ford Motor Company and is intended to promote academic leadership and research excellence.

After earning her PhD from Michigan's EECS department in 1996, Professor **Anna Stefanopoulou** joined the U-M faculty as an associate professor in 2000. She was promoted to professor in 2006. Since 2009, she has served as director of the Automotive Research Center. She is a fellow of ASME and of IEEE, a member of a U.S. National Academies committee on the 2025 U.S. Light Duty Vehicle Fuel Economy Standards and has served as an associate editor of multiple journals, among other distinctions. In 2002, she was also named one of the world's most promising innovators by MIT's *Technology Review*. Stefanopoulou has co-authored the book Control of Fuel Cell Power Systems, earned 20 U.S. patents, received five best paper awards and produced more than 250 publications on the control of internal combustion engines and electrochemical processes such as fuel cells and batteries.

Endowed professorships recognize outstanding faculty members with distinguished records of teaching, research and impact.

Maria Comninou Collegiate Professor Ellen Arruda

Ellen Arruda

Maria Comninou Collegiate Professorship

Collegiate Professorships are set up to honor the professorship holders as well as the namesake of the professor (in this case, Professor **Ellen Arruda** and Professor Emerita **Maria Comninou**). They traditionally bear the name of former University faculty members who have made substantial scholarly and other contributions while at the University of Michigan. Professor Emerita Maria Comninou retired from active faculty status on June 30, 2000.

U-M ME Professor Emerita Maria Comninou

Professor Arruda has been recognized as an eminent scholar and a world leader in the areas of theoretical and experimental mechanics of molecular materials, including polymers, elastomers, composites, soft tissues and proteins, and in tissue engineering of soft tissues and tissue interfaces. Her work has made tremendous impact on improving human health and life, such as advancing technologies for the repair of the anterior cruciate ligament and development of a shock-absorbing helmet to prevent brain injury. Arruda has recently been elected a member of the National Academy of Engineering (see page 4).

Miller Faculty Scholar Kira Barton

Kira Barton

Miller Faculty Scholar

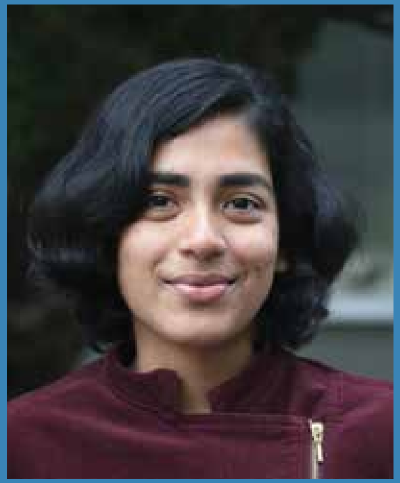
Associate Professor **Kira Barton** was selected as a Miller Faculty Scholar, earning both honorary recognition and funding for current and future research projects. This award, endowed by engineering alumnus Larry Miller, is set up to recognize junior faculty who support research in medicine and human health.

Barton's primary research focus is on precision coordination and motion control for emerging applications, with a specialization in iterative learning control. Her work intersects controls and manufacturing and combines innovative manufacturing processes with enhanced engineering capabilities. The potential impact of this research ranges from building high-resolution DNA sensors for biological applications to the integration of advanced sensing and control for rehabilitation robotics.

ME Welcomes New Faculty Members

The ME department is pleased to welcome Rohini Bala Chandran, Elliott Rouse and Alex Shorter, who are joining the faculty as assistant professors.

ROHINI BALA CHANDRAN



Bala Chandran earned her PhD in mechanical engineering from the University of Minnesota, Twin Cities. She has worked as a postdoctoral researcher in the Lawrence Berkeley National Lab. Her research endeavors have focused on solar fuels and will advance interdisciplinary research at the nexus of mechanical, chemical and materials science and engineering to overcome critical technological challenges for solar energy conversion, storage and water treatment.

Bala Chandran has developed a strong publication record on solar reactors, heat exchangers, radiative transport and reaction kinetics.

ELLIOTT ROUSE

Rouse earned his PhD in biomedical engineering from Northwestern University and has worked as an assistant professor in the colleges of Medicine and Engineering at Northwestern and as a faculty research scientist at the Shirley Ryan AbilityLab (formerly the RIC). His current research aims to discover the fundamental science that underlies human joint dynamics during locomotion, and incorporate these discoveries in a new class of wearable robotic technologies.

Rouse's research has been featured on TED, the Discovery Channel, CNN, National Public Radio, *Wired Magazine UK* and *Business Insider*.

ALEX SHORTER

Shorter earned his PhD in mechanical engineering from the University of Illinois at Urbana-Champaign. He has worked as a research engineer and postdoctoral investigator for the Woods Hole Oceanographic Institution, and was an assistant research scientist and research investigator for the University of Michigan's Mechanical Engineering department. Shorter conducts research in human movement biomechanics, assistive device design, bio-logging/comparative biomechanics and soft tissue mechanics. He has also coauthored a strong record of peer reviewed articles that have appeared in a wide range of publications.

Nine ME students receive NSF Graduate Research Fellowships

Eight ME graduate students and one ME undergraduate student have received NSF (National Science Foundation) Graduate Research Fellowships (GRF) this year. With this record, the U-M ME Department is among the ME programs nationwide with the highest number of 2017 recipients. The NSF GRF Program's goal is to increase the nation's human capacity in science and engineering by providing fellowships to early-career graduate students to support the development of a diverse and globally engaged U.S. science and engineering workforce. The recipients are:

Daniel Bruder PhD student
Advisor: **Sridhar Kota**

Andrew Davis PhD student
Advisor: **Ram Vasudevan**

Kevin Green
Undergraduate student

Megan Hathcock PhD student
Advisor: **Kon-Well Wang**

Eva Mungai Master's student
Advisor: **Jessy Grizzle**

Agnes Resto PhD student
Advisor: **Jianping Fu**

Ryan Rosario Master's student
Advisor: **Neil Dasgupta**

Adrian Sanchez PhD student
Advisor: **Ellen Arruda**

Greg Shallcross PhD student
Advisor: **Jesse Capecelatro**

Walter E. Lay Automotive Lab Interior Renovation Complete

Construction is officially complete on the interior renovation of ME's Walter E. Lay Automotive Laboratory building. The U-M College of Engineering approved an interior renovation of the space and construction began in May 2016. The project was completed in the summer of 2017.

The Auto Lab is an invaluable asset to the Department and its unique experimental facilities enable high-impact and internationally recognized research in transportation, combustion and many other fields. The building serves some 140 occupants, including faculty, staff and over 100 research students and visitors. The lab is home to several major research centers, including the Automotive Research Center (ARC), the US-China Clean Energy Research Center and the GM/University of Michigan Engine Systems Collaborative Research Laboratory. Combined, the Auto Lab annual research expenditures top $10 million.

"This project provided a much-needed facelift to the interior of the Auto Lab," said **Noel Perkins**, Donald T. Greenwood Collegiate Professor and former associate chair for facilities and planning who has led the Auto Lab renovation project. "In particular, the new lounge and meeting spaces promote the sense of community we aim for within the whole of Mechanical Engineering. We remain grateful for the support offered by the College of Engineering and to the ideas (and patience!) offered by our Auto Lab faculty, staff and students...heartfelt thanks to all."

> This project provided a much needed facelift to the interior of the Auto Lab. In particular, the new lounge and meeting spaces promote the sense of community we aim for within the whole of Mechanical Engineering.

The renovation includes updated corridors and staircases, improved lighting and display areas, a new lounge and conference rooms as well as updated restrooms and an added lactation room.

The Lab's flooring and walls received new surface finishes and the faculty and student offices were upgraded. The renovation project also included some HVAC and electrical upgrades as well.

"The outcome has been really positive and has allowed the Auto Lab occupants to have a much better working environment and to showcase their outstanding research in befitting ways," said **Kon-Well Wang**, Tim Manganello/BorgWarner Department Chair and Stephen P. Timoshenko Collegiate Professor. "This project greatly enhances the work space for, and productivity of, the faculty, students and staff and improves the experience for visitors who come from around the world to learn about the Auto Lab's programs."

Kinetic Sculpture Installed at GG Brown

Sculpture to be Dedicated to Former U-M Provost, Engineering Dean, ME Professor and U-M ME Alumnus Chuck Vest at U-M ME's 150-Year Celebration in 2018

North Campus added its most recent piece of artwork this past August and it's meant to not only catch your eye but make you think. The sculpture was installed at the entrance to the University of Michigan's Mechanical Engineering Department's GG Brown Building on Hayward Street.

The 14,000-pound, 25-foot-tall kinetic sculpture, 3 Cubes in a Seven Axis Relationship: Homage to DS and GR, 2016–2017 is the work of northern California artist Philip Stewart. It was commissioned by the U-M College of Engineering in honor of U-M ME alumnus **Charles M. Vest** (MSE ME '64, PhD '67), former dean of the College of Engineering, U-M provost and past president of both MIT and The National Academy of Engineering.

"When Chuck was dean, he had an interest in establishing a collection of artwork on the University of Michigan's North Campus," said Alice Simsar, a fine-art consultant who works with U-M. "That's why this gift in his name is so fitting."

An official dedication of the sculpture will be planned in connection with U-M ME's 150-year celebration in 2018.

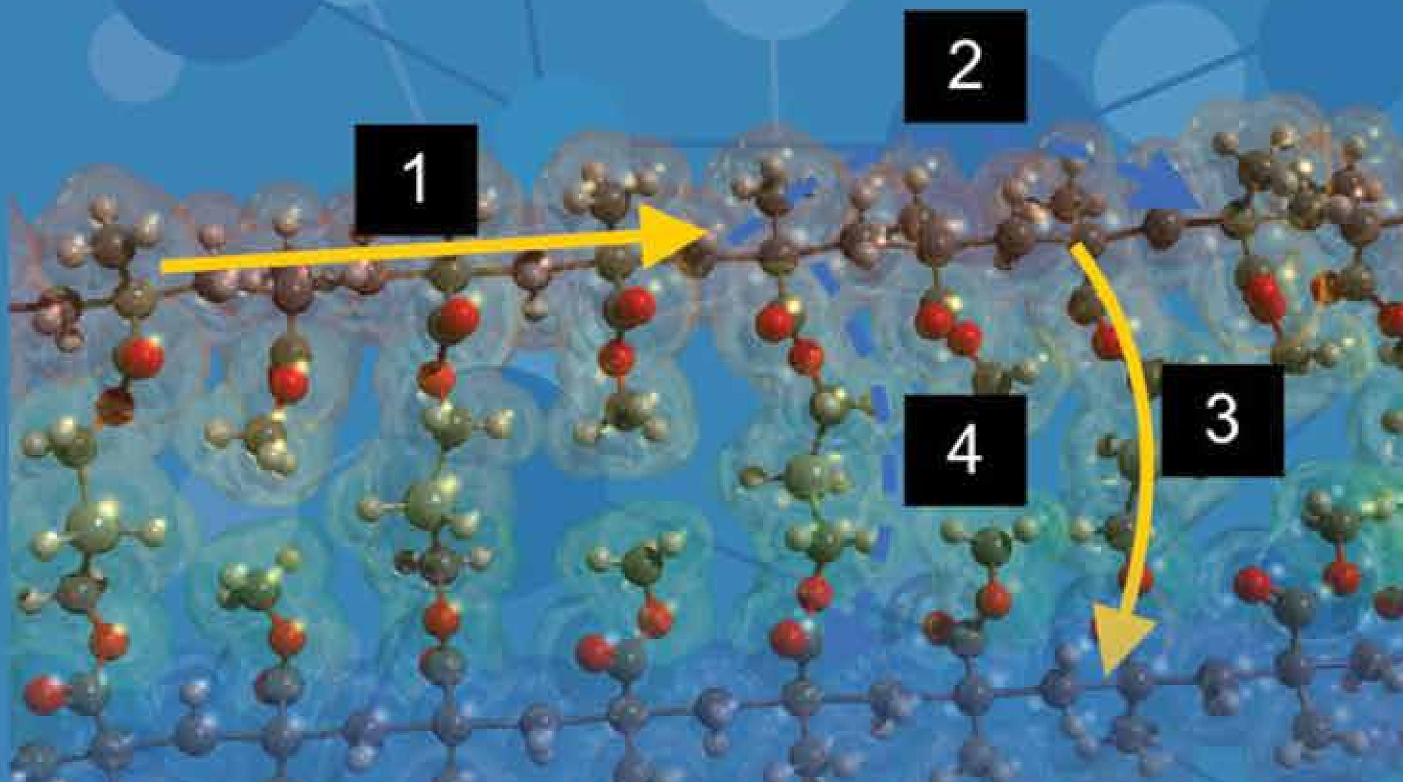
"This sculpture draws on the work of David Smith and George Rickey," said Stewart. "Smith explored the composition of simple geometric forms to imply motion. Rickey followed by introducing actual motion to the composition of simple geometric forms, and I have attempted to take the trajectory of their explorations to the next level applying 21st-century tools to the age-old process of sculpture."

3 Cubes took Stewart close to two years to complete. Much testing—including in winds as strong as 115 miles per hour—was necessary to make sure it could stand up to the elements.

"Sculpture in the built environment is incredibly important because everyone has their own relationship with it," said Stewart. "I enjoy creating pieces that engage not just one type of person, but everyone. This sculpture will be something engineers can problem-solve and three-year-olds will stare at in wonderment."

The Hayward Street entrance to GG Brown is the perfect home for the new sculpture, Stewart says. He hopes the work will inspire young engineers to think outside the box. With equal parts imagination and engineering, the possibilities are limitless.

The 14,000-pound, 25-foot-tall kinetic sculpture, "3 Cubes in a Seven Axis Relationship: Homage to DS and GR," 2016-2017, is the work of Northern Californian artist Philip Stewart (above).



Improving Heat Transfer and Energy Conversion in Polymers

Understanding how heat travels inside a material is critical to improving the performance, efficiency and reliability of the devices and systems in which it is incorporated. Thermoelectric refrigerators and power generators, heat sinks, power electronics, thermal barrier coatings and thermal interface materials all rely upon maximizing or minimizing heat transfer.

Light weight, low cost and corrosion resistance are some of the properties that make polymers ideal for use in the packaging of electronics such as smartphones or LEDs, or as structural components in cars or airplanes. However, while they have many appealing properties, they don't conduct heat well, and this, in many cases, limits their use.

> Low thermal conductivity is a main factor limiting the expanded use of polymers in new applications.

"Low thermal conductivity is a main factor limiting the expanded use of polymers in new applications," said ME Associate Professor **Kevin Pipe**. "Current plastics are thermal insulators. You can mix high thermal conductivity fillers such as metals or ceramics into a polymer to make it more conductive, but the increases in cost and weight often negate its original advantages."

MOLECULAR DESIGN

In collaboration with Materials Science and Engineering Professor **Jinsang Kim**'s group, Pipe's lab is using molecular design principles to improve thermal conductivity in polymers. While researchers have long studied how to engineer polymer molecules to have desired mechanical, electrical or optical properties (such as for use in organic LED displays), little work has focused on how to use similar principles to modify a polymer's thermal properties.

As a result, the physical properties of polymers that determine their thermal conductivity are not well understood. "We're still working to understand the fundamentals of how heat flows in polymer systems," Pipe said.

Most common polymers have a spaghetti-like molecular structure in which long polymer molecules are entangled in an amorphous rather than crystalline manner. It is generally believed that heat travels easily down the polymer backbones, but faces resistance when moving between backbones. In recent work, Pipe and Kim's groups showed that carefully created links between the backbones using hydrogen bonds could allow heat to move through the structure more easily. Their work, published in *Nature Materials* in 2015, demonstrated a tenfold improvement in thermal conductivity using this method and achieved the highest thermal conductivity yet measured in an amorphous polymer.

LEFT: Heat transfer pathways along and between polymer chains by conduction through covalent bonds or longer-range van der Waals interactions. Image: *J. Phys. Chem.* B 121, 4600 (2017).

> Polymers are **ideal for use** in certain structural components of cars or airplanes, as well as electronics packaging

Demonstrating this improvement in an amorphous polymer is important, since they are more amenable to scale-up than crystalline polymers, in which polymer chains are packed side by side in a regular pattern. While crystalline polymers are known to exhibit increases in thermal conductivity, these increases only occur in one direction (the direction of chain alignment), making them difficult to utilize in macroscale manufactured parts.

In another recent work, published in *Science Advances* in 2017, Pipe and Kim's groups increased the pH of polyelectrolytes in solution, imparting electrical charge to the individual polymer segments that caused them to uncoil due to electric repulsion. This uncoiling, as well as related increases in backbone stiffness and packing that occurred when the molecules were used to create a solid film, increased thermal conductivity by a factor of six.

In collaboration with Materials Science and Engineering Professor **John Kieffer**'s lab, Pipe's group is using computational methods such as molecular dynamics models to simulate the flow of heat between individual polymer chains.

Their recent work, published in *Journal of Physical Chemistry B* in 2017, resolved seemingly discrepant trends measured in the literature for the thermal conductivities of crosslinked polymers. The investigators showed that the role of crosslinkers in improving thermal transport is often not to act as conduits for heat conduction themselves but rather to bring the chains closer so that weaker but longer-range forces known as van der Waals interactions can transmit a larger amount of heat by involving a greater number of polymer segments (monomers).

ENHANCING THERMOELECTRIC ENERGY CONVERSION

Pipe's group has also been studying thermoelectric effects in conducting polymers to improve the efficiency with which they can perform solid-state refrigeration or harvest waste heat to create electricity.

In particular, his group has examined the doping of polymers, which is used to control electrical carrier concentration and solubility. In work published in *Nature Materials* in 2013, Pipe's group showed that excess non-conducting dopant molecules can inhibit the flow of electricity through the material; by carefully removing these excess dopants, they demonstrated the highest thermoelectric energy conversion efficiency yet achieved in a polymer or any organic semiconductor.

Pipe's work has been funded as part of the Center for Solar and Thermal Energy Conversion, an Energy Frontier Research Center funded by the US Department of Energy, Office of Science, Basic Energy Sciences; the U-M Energy Institute and Samsung.

> It's a highly flexible system that opens new doors for manufacturers, including improved remote manufacturing and improved performance and quality of multi-material manufacturing.

Improving Quality in Laser-aided Additive Manufacturing

taking ideas from basic physics and applying them to manufacturing

Additive manufacturing techniques have great potential to improve productivity and energy efficiency during part fabrication. The "bottom up" approach, creating parts layer by layer, "cuts out many steps of the traditional manufacturing process and makes it an appealing method," said **Jyotirmoy Mazumder**, Robert H. Lurie Professor of Mechanical Engineering. "But the technologies used today all fall short in the same area: inline quality control."

Even small defects in fabricated parts can have a large impact on performance and safety, that's why automotive and other manufacturers need to be on the lookout for several types of defects, including inaccuracies in part dimensions and composition, microscale cracks, porosity—small voids that can form when welding galvanized steel and weaken the weld—and others.

A number of methods exist for postmortem part analysis and inspection, but they are time- and labor-intensive, and some lack the desired degree of accuracy. They also forego a key opportunity offered by additive manufacturing: the chance to make layer-by-layer corrections while part fabrication is underway rather than after the fact.

"The current methods we have just don't give us enough information fast enough," said Mazumder, who directs the U-M Center for Laser-Aided Intelligent Manufacturing and the National Science Foundation Industry-University Cooperative Research Center for Lasers and Plasmas for Advanced Manufacturing.

Building on decades of research in materials processing and laser-aided manufacturing, Mazumder has developed and demonstrated a holistic, closed-loop system for inline quality control of laser sintering and direct metal deposition manufacturing processes.

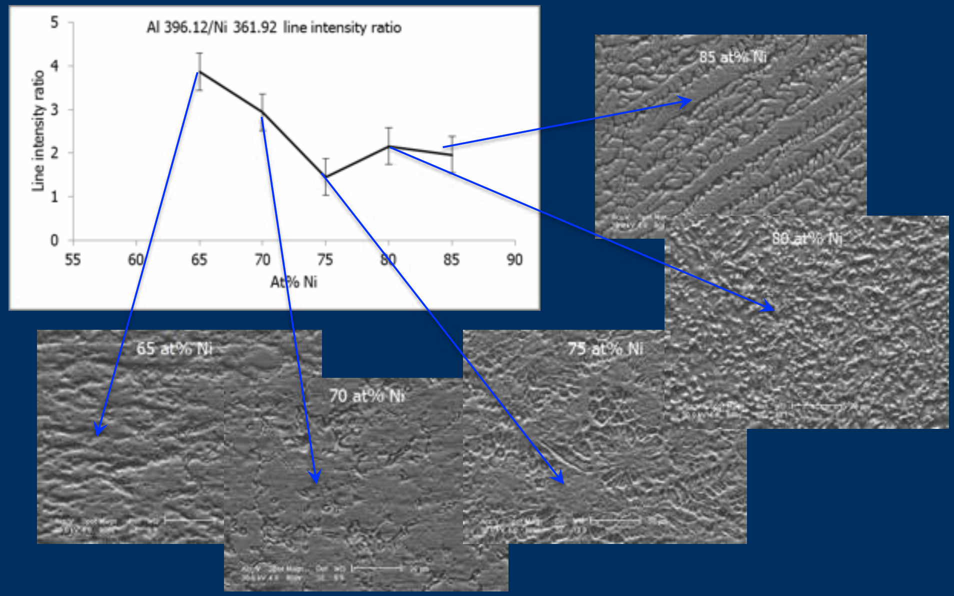
Mazumder's in-situ optical diagnostics system, dubbed the Smart Optical Manufacturing System (SOMS), is helping establish a new paradigm, "certify as you build," as he explains in an article published in 2015 in the journal *Procedia CIRP*.

The SOM system includes a number of optical sensors to detect defects and diagnose composition inconsistencies and other problems, including phase transformation. A fast-response optical sensor, based on optical emission spectroscopy, uses the plasma created by laser-aided additive manufacturing to detect pinholes, porosity and tiny cracks within milliseconds.

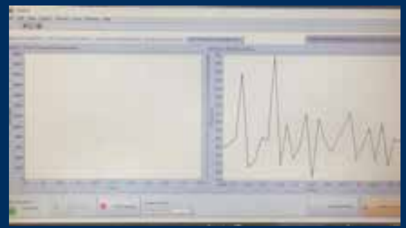
"The plasma created by the manufacturing process acts, in a sense, as a mirror that reflects what's happening at the interface between the laser and the material as well as within the material," Mazumder said. "Extracting and analyzing information with machine learning algorithms can lead us to the defects and help us make corrections."

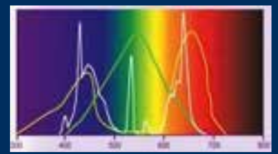
Analyzing the laser-induced plasma also provides valuable information about material composition. Similarly, using algorithms to analyze the relationship between spectral lines from different materials alerts inspectors to possible phase changes taking place as the metals are heated to high temperatures. Experimentally, Mazumder has successfully predicted the composition as well as phase transformation in a nickel-aluminum system.

The SOMS also includes sensors to monitor temperature in order to determine, and control, the cooling rate of materials.



Real-Time Process Classification





LEFT: Comparison of the conventional (upper panel) and out-of-band (lower panel) source localization. The upper panel indicates many possible source locations (red dots) and none are correct. The lower panel shows one larger red region near the actual source location at a depth of 68 meters and a range of 3 km.

"We can retrieve all kinds of information from the light very quickly," he said, "and we don't even have to be in the same facility—we can observe from a distance."

Mazumder's "certify as you build" approach incorporates technologies in a seamless way that yields capabilities greater than the sum of the individual parts. This includes identification of problems in less than a second, rather than the hours or days of conventional approaches. Identifying defects quickly enables manufacturers to course correct and prevent defects from worsening.

"We're taking ideas from basic physics and applying them to manufacturing—it's an 'atom-to-application' approach," Mazumder said. Using data from quantum mechanics and predicting properties in continuum mechanics "poses some interesting physics questions. We know it works experimentally, and now we're proving the theory."

Mazumder is also working to extend the system to determine material strength from the laser-induced plasma.

"It's a highly flexible system that opens new doors for manufacturers, including improved remote manufacturing and improved performance and quality of multi-material manufacturing," Mazumder said. "It can lower costs and reduce energy consumption—all good things that can help OEMs in a range of industries."

Funding for the work has come from the National Science Foundation, the National Institute of Standards and Technology and from industry sponsors.

Low cost is the ‘secret sauce’ to these machines, so while the technologies exist to reduce vibration in high-end, industrial printers, integrating them into consumer models would put them financially out of reach of the ordinary individual.

TOP: Scale models of US Capitol printed without vibration compensation (Top) and with vibration compensation (Bottom), leading to significant reductions in print time without sacrificing print quality.

Smarter 3D Printers: Improving Precision, Speed and Reliability at Low Cost

Over 278,000 units were sold worldwide in 2015, a 74% increase over the previous year, according to the 2016 Wohler's Report.

Three-dimensional (3D) printing is about to get smarter.

ME Associate Professor **Chinedum Okwudire's** Smart and Sustainable Automation Research Laboratory develops solutions to enable automated systems, such as industrial manufacturing and vehicle automation systems, to do more with less so users face fewer tradeoffs between precision, throughput, energy efficiency and cost.

Much of the lab's research leverages the synergies gained through mechatronics, the integration of mechanical disciplines, electronics, controls and computers. Recently the group has begun applying the same principles it uses in industrial systems to consumer-grade, desktop 3D printers.

"Some people think of these printers as toys, but they have a lot of educational and commercial uses; they're not 'just for fun,'" Okwudire said.

Adoption of consumer-grade printers, typically priced below $5,000, has been rapid. Over 278,000 units were sold worldwide in 2015, a 74% increase over the previous year, according to the 2016 Wohler's Report. But it hasn't reached its full potential.

In part that's because, at the consumer price point, users must contend with issues related to motion-induced vibration. Consumer printers tend to be constructed with light and flexible mechanical parts, which can lead to excessive vibration as the print head moves. This in turn affects the precision, speed, reliability and appearance of the printed part.

Okwudire's lab is applying its expertise in reducing vibration in engineered systems to develop new knowledge and automation solutions that address these challenges—while keeping costs down.

"Low cost is the 'secret sauce' to these machines, so while the technologies exist to reduce vibration in high-end, industrial printers, integrating them into consumer models would put them financially out of reach of the ordinary individual," he said.

Okwudire and his research team are developing a software compensation technique called filtered B-splines (FBS) that uses a priori knowledge of the printer's dynamics to mitigate vibration problems, allowing it to print faster without inducing errors. The software in effect predicts which user commands cause vibration and compensates for them proactively.

"Software compensation is not a new technique, but the challenge is how to employ it in a way that's effective, robust and versatile," he said.

The FBS technique is showing great promise in experiments, cutting print time significantly, while running at low computational cost and without any sacrifice in quality.

"The great thing about using software compensation is that it is, in a sense, free," Okwudire said.

In collaboration with ME Professor Emeritus **Galip Ulsoy**, Okwudire's team is simultaneously working to gain a deeper theoretical understanding of the FBS technique, with the goal to further improve its effectiveness, versatility and robustness. The work includes refining the technique to better accommodate uncertainty.

"We're going deep into the math and fundamentals to better understand FBS and how to apply it even more effectively," said Okwudire, who is planning to partner with desktop 3D printer manufacturers to integrate the software into their products.

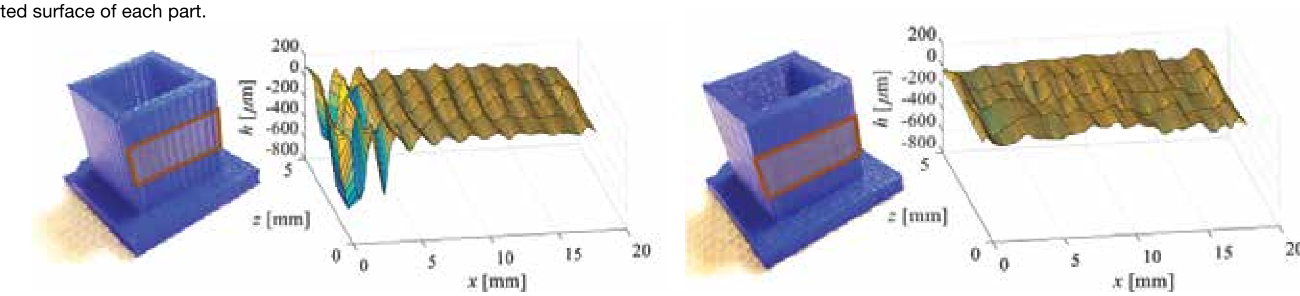
His lab also is working with experts in artificial intelligence and complex systems to create technologies to enable desktop 3D printers to gather "big data" from outside sources, including other printers and their users. The goal is for each printer to learn from the collected information to improve performance, reliability and ease of use.

These intelligent 3D printers will also be designed with architectures that allow their functionalities to be customized and enhanced through hardware and software apps, much like smartphone can be. In Okwudire's vision, the apps come not only from manufacturers but from end users and hobbyists, who are key to furthering adoption.

"What most appeals to me about desktop 3D printing is that it's a grass-roots and, no pun intended, bottom-up technology," he said. "So many ideas come from the broad base of enthusiastic users, which creates an incredible opportunity: to make 3D printers as versatile and easy to use as today's smartphones."

Okwudire has won a spate of awards for his research and teaching, including the 2016 Young Investigator Award from the International Symposium on Flexible Automation, the Outstanding Young Manufacturing Engineer Award from the Society of Manufacturing Engineers, the Ralph Teetor Educational Award from SAE International and, in 2017, an ME Department Achievement Award and the MLK Spirit Award.

BOTTOM (L-R): Surface waviness due to vibration is a common problem with parts printed on desktop 3D printers (Left). With vibration compensation (Right), surface waviness is eliminated and surface quality improved without increasing print time. Note that h represents the measured roughness of the highlighted surface of each part.



Improving Vehicle Efficiency and Self-driving Safety

Power-split hybrid powertrains, in which planetary gears connect the engine and motors, have been gaining in popularity in hybrid-electric vehicles (HEVs) in recent years, and for good reason. Power-split designs enable multi-mode operations, and their high efficiency and compact size also contribute to the appeal.

“Multi-mode, power-split hybrids are the future of HEVs,” said **Huei Peng**, Roger L. McCarthy Professor of Mechanical Engineering. “They make it possible to completely change the nature of the powertrain by switching among multiple operating modes and as a result are much more flexible in the tradeoff between fuel economy and drivability.”

But searching the design space for new and optimal HEV designs and proper component sizing yields an unwieldy number of possibilities.

Peng and his research group have developed an automated modeling methodology that searches designs to identify the optimal configuration and component size for a power-split system.

In contrast to the conventional approach, the Peng team methodology systematically searched through all possible designs, sometimes hundreds of millions of them, to identify dozens of potential designs. In simulations, the designs offered significant improvements over both launching performance and fuel economy, when compared with two popular HEVs currently in production and using identical powertrain components including the engine, battery and motors.

The industry has taken notice and several companies, including Bosch, have supported Peng’s research to apply their methodology to the design of an all-wheel drive hybrid vehicle, as well as a two-wheel-drive Class-4 truck.

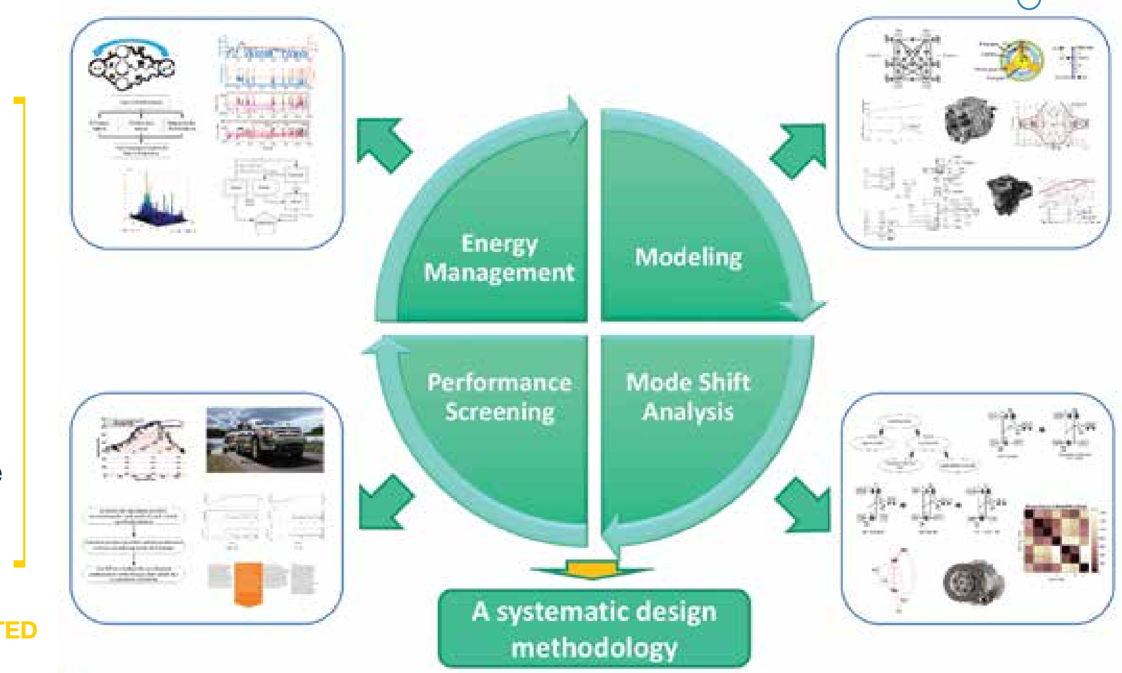
The research team searched relevant designs and vetted them for both design attributes—such as all-wheel regenerative braking—and performance attributes, including launch acceleration, towing capacity and speed range. Next, the team whittled down the list of possible designs based on fuel efficiency.

In simulations, Peng’s group demonstrated the world’s first four-wheel drive, multi-mode, power-split HEV. Their configuration uses two output shafts from the transmission, offering improved performance, independent torque control and optimal fuel efficiency. Clutches between the two planetary gears enable multiple operating modes.

The approach can be applied to other hybrid vehicle designs and, Peng believes, help grow HEV adoption.

“There are very few hybrid sport utility vehicles (SUVs) or light trucks (LTs) on the U.S. market today, even though SUVs/LTs now make up more than 60 percent of light-duty vehicle sales. All-wheel drive is going to be a key enabler of HEV adoption, giving buyers more options,” he said.

> To reach an 80 percent confidence level that automated vehicles are 90 percent safer than we humans are, test vehicles would have to be driven for more than 10 billion miles.



DRIVING SAFER AUTOMATED VEHICLES

Nearly every OEM and several technology companies are developing automated vehicle concepts. Testing those concepts is a critical step to ensuring safety, but the testing process can take a long time, in part due to the statistical rarity of crashes—about one fatality per 100 million vehicle miles traveled, according to the National Highway Traffic Safety Administration.

“To reach an 80 percent confidence level that automated vehicles are 90 percent safer than we humans are, test vehicles would have to be driven for more than 10 billion miles” said Peng, who directs Mcity, U-M’s autonomous- and connected-vehicle test facility. “We need a methodology that cuts out the non-eventful parts of driving in order to accelerate the process.”

Existing automated vehicle evaluation methods include field tests and Monte Carlo simulations, neither of which enables the investigator, statistically, to bypass the many miles driven without incident to get to the events of interest.

Peng and former graduate student **Ding Zhao**, who earned his PhD in 2016 and now serves as an assistant research scientist in the ME department, have developed a methodology that does, known as accelerated evaluation.

Peng draws an analogy to the testing of materials. “Engineers expose materials to acidity, high temperature, or high moisture, for example, to accelerate corrosion tests. Instead of humidity or acidity, we’re looking at the aggressive moves of other drivers and cars, such as cutting off the automated vehicle during a lane change,” he explained. “In statistical terms, we’re using importance sampling rather than uniform sampling.”

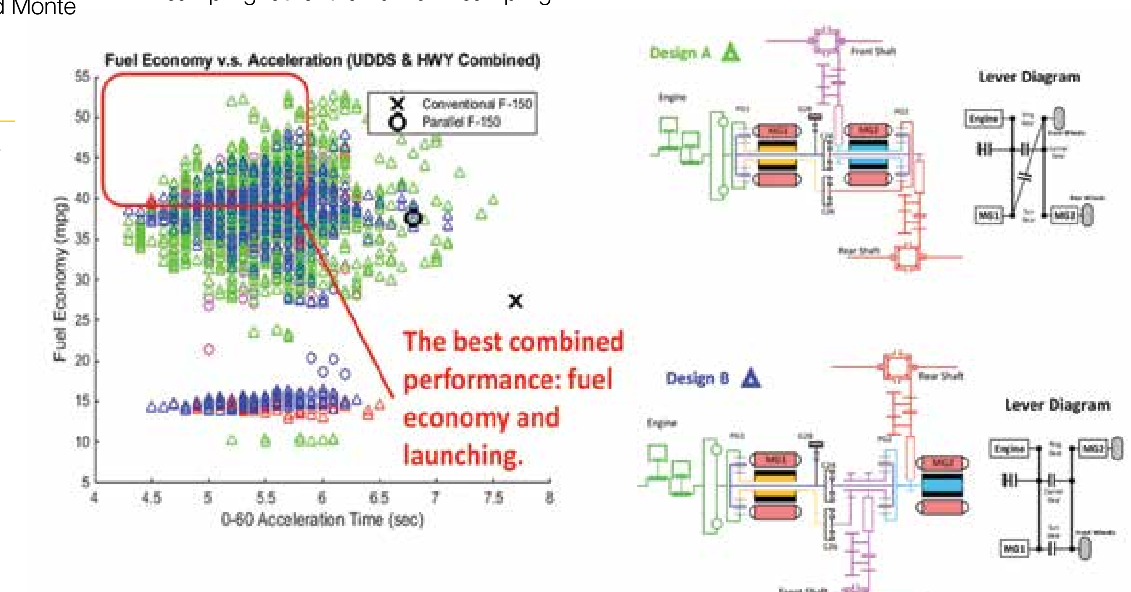
The accelerated evaluation methodology includes naturalistic driving data from over 25 million miles traveled, new models and simulations of challenging situations and aggressive moves of human drivers in other vehicles and statistical insights into realistic benefits and risks.

The methodology sped up the testing process by between 300 and 100,000 times, two to four orders of magnitude. Plans are in place to implement accelerated evaluation at Mcity in the coming months.

“We’re planning to have a robotic vehicle that implements the new statistics,” Peng said, “and we’ll make sure that the autonomous vehicles tested here are challenged by our aggressive robotic driver, so that the validation test is done in shorter time and at much lower cost.”

TOP: A four-step process was developed for systematic and exhaustive search of all possible hybrid powertrain designs.

BOTTOM: Using the developed design process, Peng’s team successfully identified two families of powertrains that are all-wheel-drive, and achieve better fuel economy and driving performance compared with the original two-wheel-drive benchmark.



Wearable Tech to Quantify Human Performance in the Field

Most biomechanics research takes place in laboratory settings, in part because conventional approaches, such as optical motion capture, require reflective markers and substantial calibration to effectively measure human movement. This makes them ineffective for working in the field.

Noel Perkins, Donald T. Greenwood Collegiate Professor and Arthur F. Thurnau Professor in Mechanical Engineering, is helping researchers break free of that constraint.

In a three-year research project sponsored by the U.S. Army, Perkins and his team are developing an automated measurement system to quantify the physical performance of individuals as they move through an outdoor obstacle course.

The Army uses performance on such courses to understand whether soldiers are adequately trained for the situations and environments they may face and how their performance is impacted by the gear they carry.

"If you only look at gait or how long it takes to complete a particular obstacle to assess performance, you miss a lot of the biomechanical movements that are responsible for it," Perkins said.

Instead, researchers in his laboratory, with colleagues in Professor Leia Stirling's laboratory at the Massachusetts Institute of Technology, are using measurement techniques based on wireless inertial measurement units, or IMUs.

The small, low-cost, lightweight sensors contain accelerometers, gyroscopes and magnetometers and eliminate many experimental constraints, since they don't require external reference points for dead reckoning.

"If you put these on the body, you can now measure the motion of all major body segments simultaneously and outside a lab," Perkins said.

For example, Research Investigator Dr. **Stephen Cain** is working to quantify soldier performance on balance beam, window and wall obstacles. In the case of the balance beam, performance assessment has traditionally consisted of two metrics: time to move across the beam and whether the individual did so without falling.

Cain is using more than a dozen sensors attached to the body, helmet and a mock rifle. Early analysis employed data from the feet, pelvis and torso—a choice based both on data reliability and observation after video analysis revealed that study participants primarily used step placement and left and right body lean to correct their balance.

From the torso sensor data, he determined how far subjects leaned, the frequency, duration and whether leaning occurred while moving quickly or slowly. While many performance metrics can be derived from the measured data, the most predictive metric of balance performance was the variability of the size of balance corrections that a participant used when crossing the beam.

Doctoral candidate **Rachel Vitali** is focusing on using IMU data to estimate three-dimensional rotations across the human knee joint. She does so by utilizing data collected simultaneously from two strategically placed IMUs: one attached to the thigh and one attached to the shank.

Measurements from these IMUs are ultimately fused to reconstruct the orientation of the shank relative to the thigh, which in turn provides the three rotation angles across the knee, namely flexion/extension, abduction/adduction and internal/external rotation. The key to this advance is exploiting the constraint that the knee acts largely as a hinge joint during many types of identifiable motions.

In benchmarking experiments using a coordinate measurement machine, Vitali has proven her method. "Our next step is to extend the work to encompass the subtle complexities of a human knee," she said.

3-year research project sponsored by the U.S. Army.

Michael Potter, PhD pre-candidate, looks at running and sprinting performance with IMU data from sensors on participants' feet. To estimate the full trajectory of each foot, the IMU data is integrated forward in time but doing so also introduces errors from sensor drift. To overcome drift, Potter has developed algorithms that use zero-velocity updates (ZUPTs), which reduce drift by assuming the foot is stationary, at least briefly, during the stance phase of each stride.

The technique has proven accurate for walking, but little research has validated it for running. Potter first observed large differences between estimates of total distance run and known distances. He conducted tests to determine the source of the discrepancies, and early results point to sensor limitations, particularly due to lower accelerometer ranges and/or sampling rates.

> Whether you're generally a slower runner or a faster runner, your speed is limited by the next step. So if you speed up, you may overshoot the step; if you slow down, you may undershoot.

"Now we're working on a larger study so we can better understand the sensor requirements for accurate results at various speeds," he said.

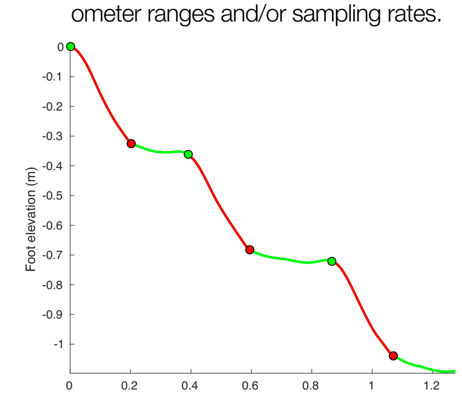
Assistant Research Scientist **Lauro Ojeda** is quantifying performance of running on stairs. Research using optical motion capture has relied on observations of very few steps. "Unfortunately, you can't get to a steady state, nor can you study this in the field."

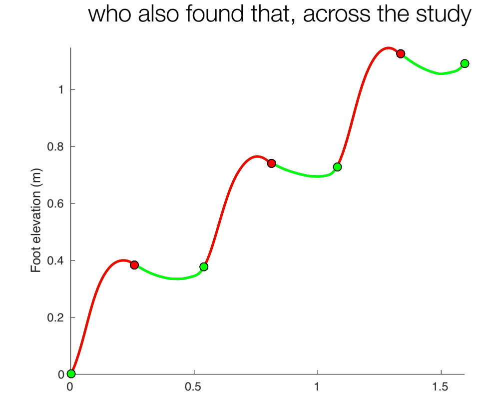
Ojeda's data, collected as participants run up and down a full flight, has shown that when ascending, individuals tend to run. That is, they have both feet airborne during one phase of their stride. On the descent, however, data showed many instances of a double-support phase, during which both feet supported the body.

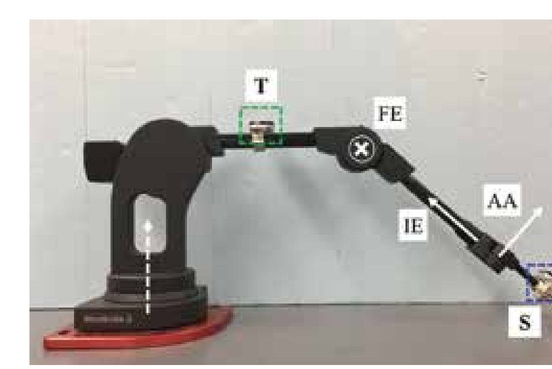
"As we suspected, it's easier for people to run up stairs than down," said Ojeda, who also found that, across the study population, individuals' speed between steps was fairly constant. "Whether you're generally a slower runner or a faster runner, your speed is limited by the next step. So if you speed up, you may overshoot the step; if you slow down, you may undershoot."

In the end, the comprehensive automated system will include wearable technology, algorithms and a tablet-based app with at-a-glance metrics. "With this technology," Perkins said, "we can identify fine-grain movements and develop metrics that really capture the essence of performance."

FAR LEFT, TOP: Body-worn array of inertial measurement units (IMUs) reveal human movement.
FAR LEFT BOTTOM: Shoe-mounted IMUs are used to study performance while running a staircase.
TOP RIGHT: Participant running a challenging balance beam embedded in an outdoor obstacle course.
BOTTOM (L-R): Estimated foot trajectory while running and descending (left) and ascending (right) a staircase. IMUs attached to a coordinate measuring machine to simulate the three-dimensional rotations across the human knee joint.







Gaining New Insights Into Multiphase Flows: Bubbly Shock Waves & Superhydrophobic Surfaces

In his internationally recognized laboratory, **Steve Ceccio**, the Vincent T. and Gloria M. Gorguze Professor of Engineering, conducts novel experiments to better understand the complex dynamics of cavitation and other multiphase bubbly flows at the macro and micro scales.

Cavitation refers to the formation of bubbles when liquid changes to vapor in response to a sudden drop in pressure. The phenomenon occurs in many situations, including within narrow flow passages and around ship propeller blades as they move through the water. As the water flow speeds up, the local pressure drops and, if it drops enough, tiny bubbles can grow explosively and collapse, causing performance degradation, noise and vibration and erosion near the cavitating surfaces.

"Cavitation isn't all bad. It's been employed for beneficial medical purposes, sometimes deliberately produced through ultrasound, but in hydraulic systems it's something we usually want to prevent," Ceccio said. "To understand its effects, we need to see exactly what's going on in the cavitating flow itself."

IMAGING THROUGH A BUBBLY CLOUD

One key challenge to visualizing cavitation is the high gas-volume fraction. Ceccio likens the effect to examining a glass of champagne or beer: "You have a lot of nice bubbles, but the bubbly clouds can easily make the liquid opaque."

ABOVE: A towed axisymmetric model is tested in the U-M Marine Hydrodynamics Laboratory to determine the amount of skin friction reduction achieved through application of Super Hydrophobic Coatings on its surface.

You have a lot of nice bubbles, but the bubbly clouds can easily make the liquid opaque

Even a volume-fraction of a few percent can defeat optical probes of these bubbly liquids, but in many cavitation flows, the volume-fraction can reach over 30 percent. So Ceccio and his team turned to X-ray technology. The group has developed a specialized cinematographic X-ray densitometry and imaging system to penetrate the bubbly liquid and directly measure cavitation dynamics. His is one of the first research teams in the country to observe and capture the dynamics of cavitating clouds at rates in excess of 1000 frames per second.

Ceccio's team used the system to examine the growth and shedding of vapor-filled pockets, analogous to the sheet cavities that form on pump and propeller blades. When the first images came in, they were surprised to see what looked like shock waves within the shedding cavity cloud.

"The classical explanation for cavity shedding is the presence of a liquid jet forming where the cavity closes on the surface. But we observed bubbly shock wave propagation within the cavity that led to shedding," he explained.

Since the bubbly cloud is compressible, the presence of shock waves had been predicted theoretically. But the X-ray images revealed them directly.

Ceccio's group subsequently showed that cavity dynamics are strongly related to the Mach number within the bubbly cavity, with the strongest shedding associated with hypersonic conditions.

"Now that we know more about the importance of compressibility in these flow dynamics, we can begin to reinterpret a variety of curious cavitating phenomena," said Ceccio, whose group now is at work on a scanning X-ray tomography system.

SMALL BUBBLES LEAD TO FRICTION DRAG REDUCTION

Many passive and active technologies have been studied in recent decades to reduce skin friction produced by turbulent liquid flows, another area of interest to Ceccio. Reducing skin friction can lead to increased system performance and lower energy consumption.

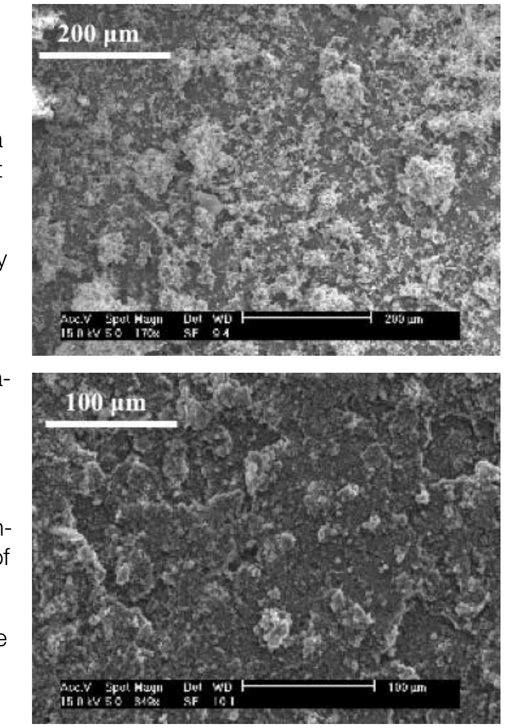
One promising possibility is the use of superhydrophobic surfaces (SHSs). Much like lotus leaves whose nanoscale surface features keep the leaves dry by causing water to bead up and roll off, engineered SHSs can have a similar effect. The surfaces have micro- and nanoscale textures that trap small pockets of gas, which can reduce the local skin friction produced by liquids flowing over them. What has remained unclear, however, is whether these surfaces could reduce the friction of turbulent flows.

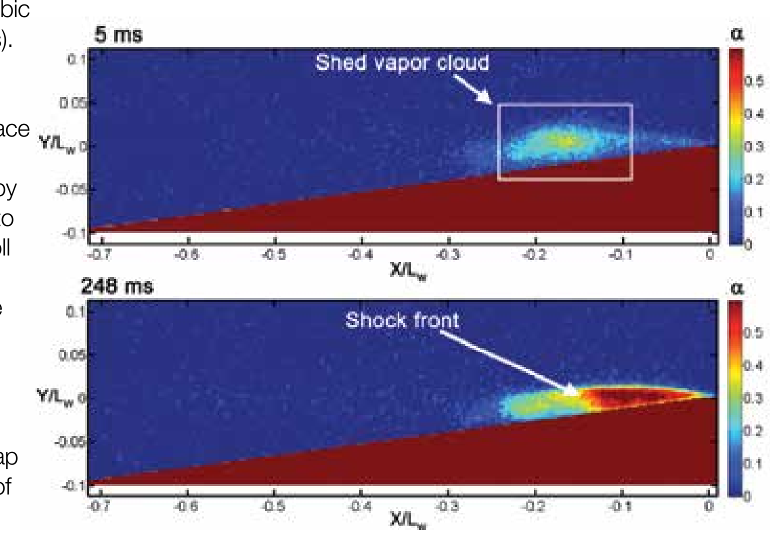
In a large, five-year effort to explore this question, Ceccio serves as principal investigator of a Multidisciplinary University Research Initiatives program supported by the U.S. Office of Naval Research. A team of experts from U-M as well as Massachusetts Institute of Technology, Stanford, University of Minnesota, Johns Hopkins and The University of Texas at Dallas have developed a wide range of SHSs and characterized their interactions with the turbulent flow.

The team has presented some significant findings. The SHSs can, indeed, lead to meaningful reductions—up to 50 percent—in the skin friction drag of turbulent flows, so long as the SHSs maintain the small gas pockets within their microscale surface features. When the bubbles remain stable or replenish, friction reductions persist. But when the gas pockets are lost, friction readily returns.

Ceccio's team is now working to show that SHS coatings can reduce friction on a towed axisymmetric body in U-M's Marine Hydrodynamics Laboratory.

Now that we know more about the importance of compressibility in these flow dynamics, we can begin to reinterpret a variety of curious cavitating phenomena.





TOP: Images of two super-hydrophobic surfaces studied as part of the MURI prepared by Prof. Tuteja's research group at UM.

BOTTOM: X-ray visualization of a leading-edge vapor cavity showing the formation of a shock wave.

As engineers trying to solve a problem, we have to carefully consider the broader context of the design problem and elicit product requirements from a wide variety of stakeholders.

Designing Technological Solutions to Health Challenges

TOP: Ibrahim Mohedas demonstrates the SubQ Assist prototype to clinical partners at the St. Paul's Hospital Millennium Medical College in Addis Ababa, Ethiopia to elicit feedback about the design concept.
BOTTOM: The smartphone balance trainer provides vibrotactile cues to the user's torso during a challenging balance task.

Stakeholder engagement throughout the front-end design process, in addition to the verification and validation processes, is crucial to developing effective healthcare technologies that truly address needs and improve quality of life.

"That's true no matter where or with whom engineering designers are working. As engineers trying to solve a problem, we have to carefully consider the broader context of the design problem and elicit product requirements from a wide variety of stakeholders, including physicians, nurses, patients, procurement officers, biomedical technicians, Ministry of Health officials and others," said ME Associate Professor **Kathleen Sienko**, a Miller Faculty Scholar and Arthur F. Thurnau Professor.

Sienko directs a multidisciplinary laboratory focused on developing and applying novel methodologies to create technological solutions that address pressing societal needs at the intersection of health care and engineering. The Sienko Research Group is tackling health-related challenges within both high- and low-income country settings, spanning topics that include rehabilitation engineering, maternal health, and motion sickness mitigation strategies for autonomous vehicles.

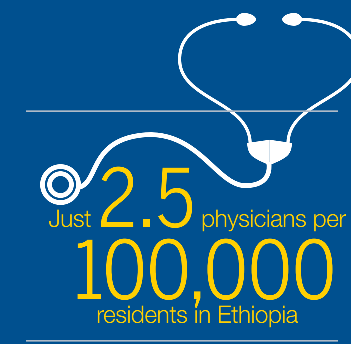
FINDING BALANCE

As we age, our sense of balance erodes, leading to not only a heightened risk of falls but also an increased fear of falling. Both have a large impact on seniors' mobility, quality of life and ability to live independently.

Targeted exercise programs can help improve balance in individuals with balance issues, and research suggests that supervision by skilled clinicians, such as physical therapists or exercise physiologists who provide immediate feedback on the movements performed, contributes to this benefit.

"There can be a lot of barriers for older people who want to improve their balance and reduce their risk of falling," said Catherine Kinnaird, engineering technician with the Sienko Research Group. These barriers can include insurance limitations, transportation and other factors that impede access to professionals.

Building on Sienko's earlier work, her research group is investigating the role of at-home training with sensory augmentation, employing a smartphone-based balance training device to provide vibrotactile cues to a user that indicate how his or her body is swaying during an exercise session.



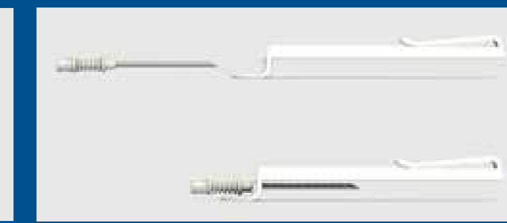
Development of the training device (as detailed in a highly cited 2012 *Journal of NeuroEngineering and Rehabilitation* article) involved engineers, older adults and patients with vestibular deficits and physical therapists. The most recent version of the device comprises two iPods, one used as a sensing device and the other as a user-control device. The balance trainer delivers vibrotactile cues through four actuators, or "tactors," placed on the user's torso. Users move in response to better stabilize their motion.

Three recent studies by Sienko's group that involve older adults, individuals with vestibular deficits and people with cerebellar ataxias are the first to examine the effects of long-term balance training, i.e., six to eight weeks, with or without sensory augmentation. The studies are also the first to include follow-up assessments at six months. Preliminary findings suggest that sensory augmentation can indeed improve balance outcomes beyond those achieved by balance training alone—and potentially sustain these improvements even without continued use of sensory augmentation.

The work, performed in collaboration with investigators at the University of Pittsburgh and the U-M Department of Otolaryngology, Department of Neurology and School of Kinesiology, has been funded by the National Institutes of Health, National Science Foundation, U-M MiBrain Initiative, U-M Pepper Center and Babcox Research Fund Pilot Award.

TASK SHIFTING TO IMPROVE ACCESS TO CARE

While about half of married women of child-bearing age in sub-Saharan Africa would like to space or limit pregnancies, about one-quarter don't have access to long-term means for contraception such as contraceptive implants. In Ethiopia—and other low- and middle-income countries—a major obstacle is the shortage of trained healthcare providers, with just 2.5 physicians per 100,000 residents. Women in rural areas have even less access.



In an effort led by postdoctoral fellow **Dr. Ibrahim Mohedas** (PhD ME '16), the Sienko Research Group has developed a device, called SubQ Assist, to safely task-shift contraceptive implant insertion from clinicians to community health workers, thereby improving access.

Currently, Mohedas explained, trained healthcare providers insert contraceptive implants free-hand, using a large-bore needle to deploy the implant just under the skin of the underside of the upper arm, above the subcutaneous fat layer. Without adequate training on the technique, however, the implant may be placed too deeply, penetrating the fat layer or muscle. In these cases, removal requires costly imaging and surgical procedures that raise the risk of complications.

The need for the device was identified and defined through extensive design ethnography fieldwork performed in Ethiopia, Ghana and Rwanda since 2013.

Working in tandem, students and clinicians at U-M and St. Paul's Hospital Millennium Medical College in Addis Ababa co-developed the device. Additional fieldwork performed in collaboration with the University of Gondar and input from end users led to subsequent design refinements.

"This iterative, collaborative process enabled our team to align design requirements with an established need defined by the Ministry of Health and by end-users, and to continue to develop SubQ Assist in accordance with the country's regulatory requirements," Mohedas said.

SubQ Assist won first place at the 2017 Global Health & Innovation Conference Pitch Contest.

Pre-clinical trials are underway, and the team is working toward a clinical trial and identifying potential partners for commercialization.

Funding for the work has come from the USAID Saving Lives at Birth program, Grand Challenges Canada and VentureWell. The Sienko Research Group is using a similar design process to create task-shifting devices to facilitate implant removal as well.

TOP: The SubQ Assist is a simple, injection molded device that acts like a template for minimally trained healthcare providers. The housing of the device can be clipped to a standard blood pressure cuff and wrapped around the upper arm. When the cuff is inflated, it pushes the skin and subcutaneous tissue into the device's cavity and the guide on the front of the device ensures that the implant needle is accurately inserted below the surface of the skin and parallel to the arm.
BOTTOM: Ghanaian clinicians evaluate a contraceptive implant removal prototype.

> We hope the system our team has demonstrated and the models the team is creating will help speed understanding of nanoparticle uptake and bring us closer to new therapies and delivery methods as well as reduce inadvertent exposure risk.

Understanding the Biologic Uptake of Nanoparticles

The material cerium oxide (CeO_2) is being used in an increasing number of applications: as a diesel fuel additive to prevent the formation of soot during combustion, in diesel after-treatment systems as well as in medical therapies to treat some types of cancer and ophthalmic conditions. The growing use of CeO_2 and other nanoparticles means increased exposure risk, both deliberate and incidental.

"As more of the devices and items we use every day contain or release nanoparticles like CeO_2, there's a real impetus to understand and develop models to predict their distribution in the environment and their uptake by the human body," said Professor **Margaret Wooldridge**.

To date, there has been little whole-body, in vivo research looking at the biological uptake of CeO_2 nanoparticles through inhalation, and much of the research that does exist has used nanoparticles that were not isolated from other substances. Nor has previous work fully accounted for how the particles age under natural conditions, such as exposure to ultraviolet (UV) radiation from the sun.

With colleagues Dr. **Dingsheng Li**, Dr. **Masako Morishita**, **James Barres** and Professor **Olivier Jolliet** in the U-M School of Public Health Department of Environmental Health Sciences and Professor James Wagner at Michigan State University, Wooldridge is advancing our understanding of CeO_2 nanoparticle aging and biological uptake in a collaborative, two-part research initiative.

> **One of those applications is drug delivery, including for Alzheimer's and other diseases that affect the brain**

Over the past two decades, the Wooldridge research group has demonstrated synthesis of a broad range of nanoparticles, including pure metals and several different types of metal oxides.

In work published in 2017 in the *Journal of Aerosol Science*, Wooldridge and research scientists Dr. **Mohammad Fatouraie** and Dr. **Ethan Eagle** led development of a combustion system and method to generate CeO_2 nanoparticles for research studies in a way that minimizes the handling and processing that can change particle properties.

The system Wooldridge and colleagues demonstrated continuously produced CeO_2 nanoparticles over the course of several hours with controlled and consistent size, concentration, shape and structure. The system also included an aging chamber to expose the particles to UV light.

In their study, the team found that particle size and structure showed little sensitivity to the UV light within the aging chamber. This suggests that other pollutants in the environment, or produced in diesel fuel systems, contributed to the particle aging detected in previous research efforts.

Following demonstration of the particle synthesis and aging system, the team next conducted an in vivo inhalation exposure study in an animal model. The investigators found that shortly (less than 30 minutes) after a two- or four-hour inhalation exposure, CeO_2 nanoparticles could be detected in multiple tissues in addition to the lungs, including the brain, heart, liver and kidneys.

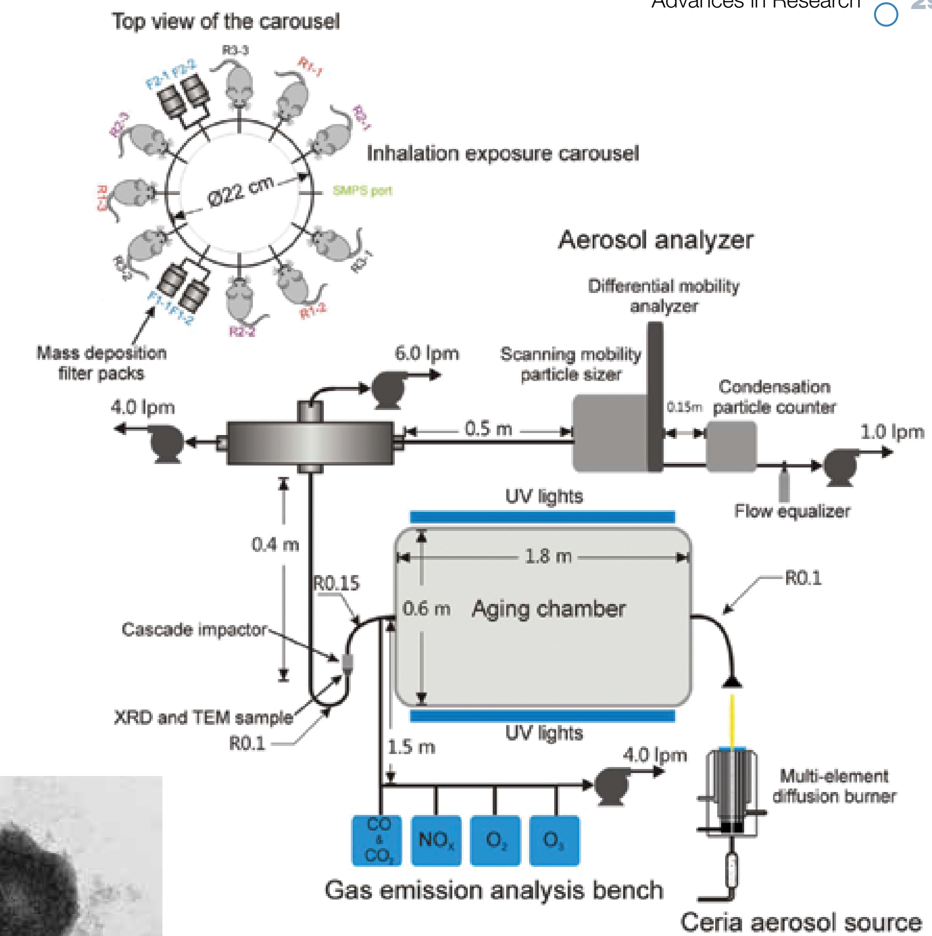
"The findings of such rapid uptake and biodistribution of nanoparticles were remarkable," Wooldridge said, "and important for us to understand when we think about the use of CeO_2 and other types of nanoparticles for existing and new applications."

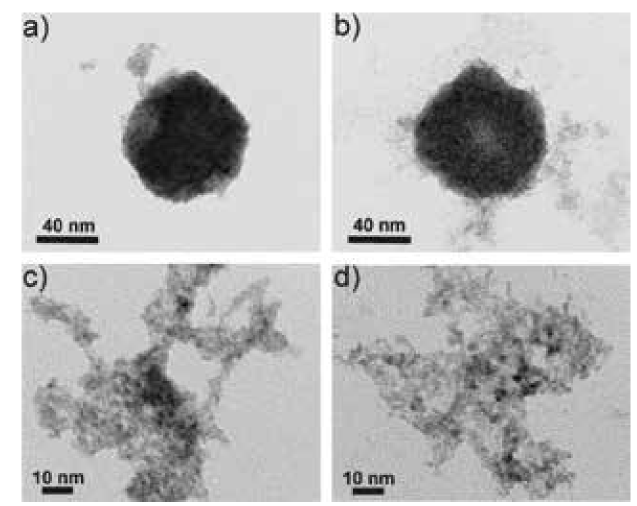
One of those applications is drug delivery, including for Alzheimer's and other diseases that affect the brain.

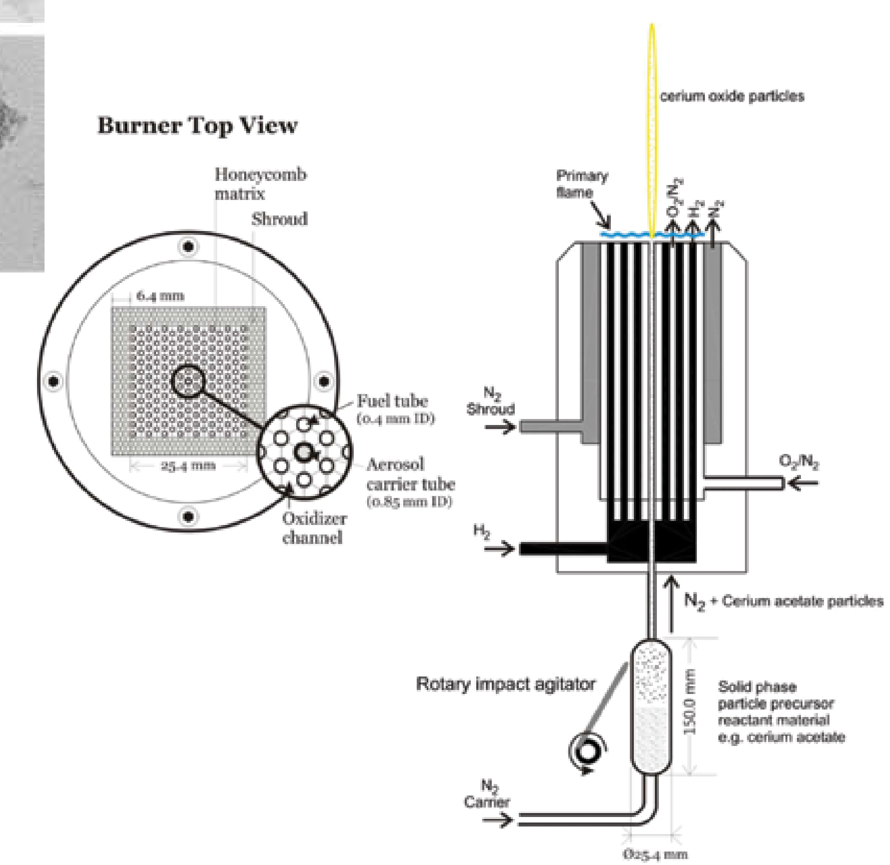
"Currently, the data from other studies related to CeO_2 toxicity has been mixed," Wooldridge added, "which highlights the need for further research.

"We hope the system our team has demonstrated and the models the team is creating will help speed understanding of nanoparticle uptake and bring us closer to new therapies and delivery methods as well as reduce inadvertent exposure risk," she said.

Wooldridge believes the collaborative approach was the linchpin of the team's impactful findings. "We have experts in inhalation exposure studies, in the atmospheric conditioning of aerosols and, on the combustion side, in generating and characterizing nanoparticle aerosols. This kind of work can only happen with such a multidisciplinary group."







ABOVE: Bright field TEM images of typical CeO_2 particles. a) non-UV-aged particles at 50000× magnification; b) UV-aged particles at 50000× magnification; c) non-UV-aged particles at 200000× magnification; d) UV-aged particles at 200000× magnification.

TOP RIGHT: Schematic of the integrated nanoparticle synthesis, aging chamber and aerosol delivery system.

BOTTOM RIGHT: Schematic of the combustion synthesis source of the ceria nanoparticles.

New Microscale Tools to Understand
Cell Properties, Sensing and Behavior

> Compression is a form of deformation not often studied by biologists. But as a tumor grows in the body's tissue, it exerts compressive stress. A device like this helps us more accurately model the mechanical perturbation cells might experience in the presence of cancer.

Understanding how cells sense, and react to, mechanical input requires new microscale tools and methods, including new devices that can apply forces to one cell at a time.

"When you're working at the single cell level, we need to be able to consistently apply forces and measure how each individual cell deforms, which tells us a lot about its mechanical properties," said ME Assistant Professor **Allen Liu**, who directs the U-M Laboratory of Cellular and Molecular Systems.

Liu uses a conventional technique, micropipette aspiration. Much like sucking on a straw to apply negative pressure that draws elastic material inside, micropipette aspiration applies negative pressure to a single cell. The stiffer the cell, the less it is drawn into the pipette. But the technique presents several challenges, including training, consistency, cost and low throughput.

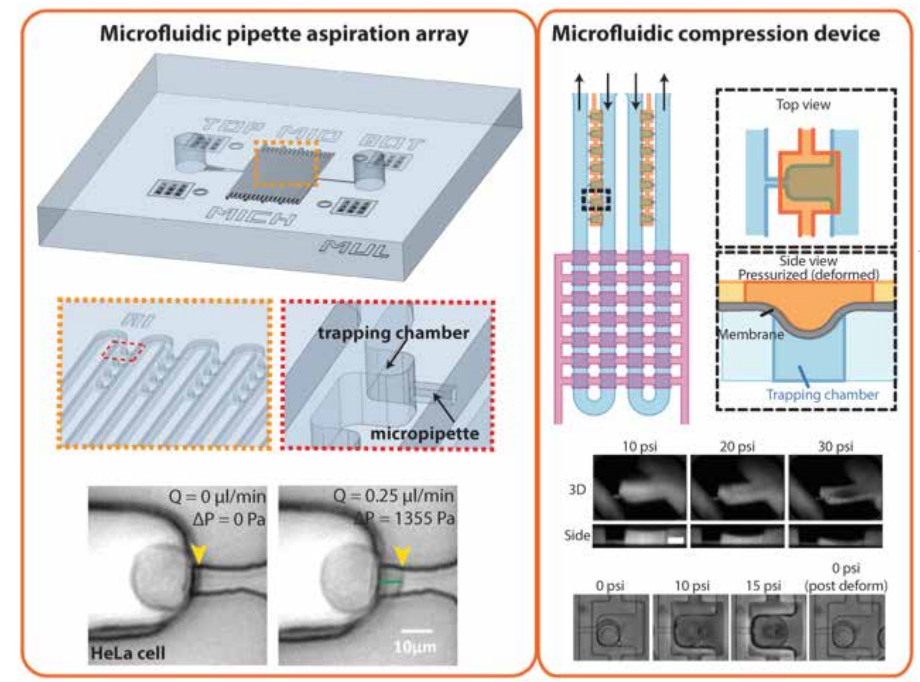
"It takes about 15 minutes to handle and measure one cell, which is why we wanted to create a microfluidics solution that could improve the throughput as well as minimize issues that arise from inconsistent handling and environmental conditions," Liu said.

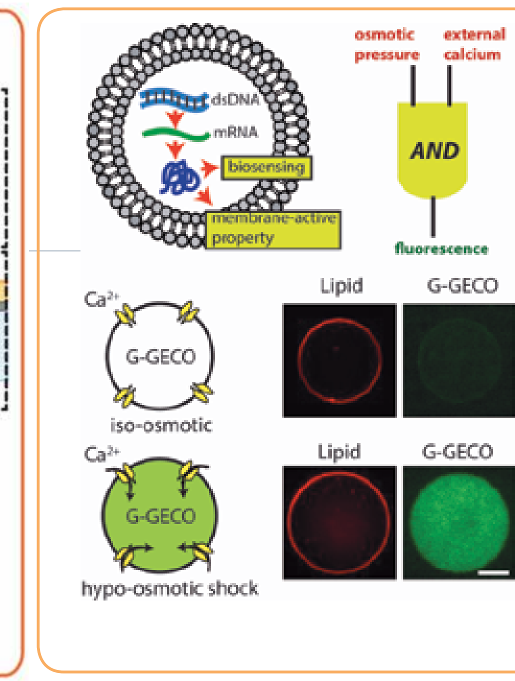
In work published in 2015 in the journal *Lab on a Chip*, Liu and his research team demonstrated such a solution, a microfluidic chip that traps an array of 20 single cells. Using a syringe pump to change the volume flow rate, the device applies negative pressure in parallel to all of the trapped cells. An optical microscope is used to measure the amount of deformation and protrusion into the pipette, and automated image analysis quantifies key geometric parameters of the cell.

In addition to microfabricating the chip using soft-lithography techniques, Liu's group performed modeling and experimentally validated their work. With the device, Liu and his team measured the stiffness of breast cancer cells and compared them with the stiffness of healthy epithelial cells. They found that healthier cells were stiffer than the cancer cells, a finding supported by previous research. Some types of cancer cells have been shown to deform significantly, which may enable them to better travel through tissue and proliferate.

Liu's group also used the device to better understand the gating threshold of the mechanosensitive channel found in many bacteria. Mechanosensitive channels serve as "emergency release valves," Liu said, when bacteria take in too much water from their environment, much like a bathtub drain lever opens the drain valve so a full tub can empty.

In further work published in 2016 in *Scientific Reports*, Liu refined the device, adding a mechanical valve that applies compression force to the trapped cells from the top with a silicone membrane.





"Compression is a form of deformation not often studied by biologists," Liu said. "But as a tumor grows in the body's tissue, it exerts compressive stress. A device like this helps us more accurately model the mechanical perturbation cells might experience in the presence of cancer."

Liu's device is the first with the capability to apply two types of forces, aspiration and compression, in parallel at the single-cell level. In ongoing work, his team is studying how mechanical compression affects cancer cell proliferation and signaling.

BUILDING ARTIFICIAL CELL SYSTEMS

Liu's interest in mechanotransduction also has led him to develop artificial cell systems that can sense mechanical inputs and respond with a biochemical output. In work published in the journal *ChemComm* (Chemical Communications) in 2017 and featured in the Emerging Investigator Special Issue, he was the first to demonstrate an engineered, mechanosensitive lipid vesicle that can sense, process and respond to both mechanical and chemical inputs.

Again, Liu's work has been influenced by bacterial mechanosensitive channels of large conductance, MscL, which open about two nanometers to allow material to escape from the cell.

"It's a very clever mechanism that evolved about 3.5 billion years ago," said Liu, who was inspired to incorporate the mechanosensitive bacterial (in this case, E. coli) membrane protein MscL into his engineered system.

In addition to the lipid bilayer and mechanosensitive channel, Liu's cell-sized system includes an engineered, fluorescence-based calcium-ion sensor, also expressed inside the vesicle. The *in vitro* system used encapsulated cell-free transcription translation, an increasingly popular technique known as TXTL.

"TXTL is a versatile, powerful platform that enables us to produce any proteins of interest and opens the door for engineering artificial cells in a modular fashion," he said.

Liu's work has been funded by a 2012 National Institutes of Health Director's New Innovator Award and by the National Science Foundation.

TOP LEFT: Microfluidic tools for single cell mechanical perturbation: aspiration (left) and compression (right).

TOP RIGHT: DNA-programmed artificial cells capable of AND-gate logic with osmotic pressure and external calcium as inputs.

Patterning and Morphology
in Biological and Nonliving Systems

Understanding the ways in which materials deform and develop stresses and how they respond to those stresses is relevant both to biological as well as nonliving systems, including lithium-ion batteries, other semiconducting devices and alloys used for structural applications, such as automobiles, aircraft and buildings. Chemistry, too, plays a role, impacting both living and nonliving systems in important—but not yet fully understood—ways.

"Chemistry affects mechanics, and mechanics affect chemistry," said ME Professor **Krishna Garikipati**, who also holds an appointment in mathematics. Intercalation, the process of atoms being inserted between atomic planes in a crystal lattice, in lithium-ion batteries clearly demonstrates his point.

"Every time we charge our phones, lithium atoms lodge themselves in the battery's crystal structure and cause it to swell. This happens over and over as we charge and discharge the battery. Eventually, the battery develops microscopic cracks that degrade its ability to hold a charge. There's a lot of electrochemistry taking place that contributes to the material's mechanical failure," he said.

In biological systems, Garikipati's work at the intersection of mechanics and chemistry—as well as mathematics and physics—has recently focused on patterning and morphology, or the study of form, size, structure and positioning in living systems. Spots on a butterfly's wings, the patterns on a leopard's or snake's skin, precisely where a wing protrudes from an insect's thorax—we see countless examples every day.

How biological systems sense size and position, both critical to patterning and three-dimensional development, is a central question in the field of developmental biology.

Take eye color, for example. "In order for cells in the iris to be able to implement the developmental blueprints contained in their chromosomes, they need to know where they are so that they develop the right features—color, for instance—at the right size in the right place," Garikipati explained.

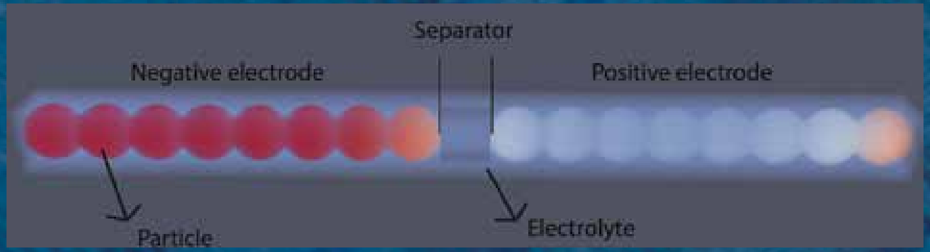
So how are size and position determined? Cells carry genetic instructions in their DNA, and the process by which DNA is transcribed to produce proteins that carry out specific functions is increasingly well understood. But these processes alone don't tell the whole story.

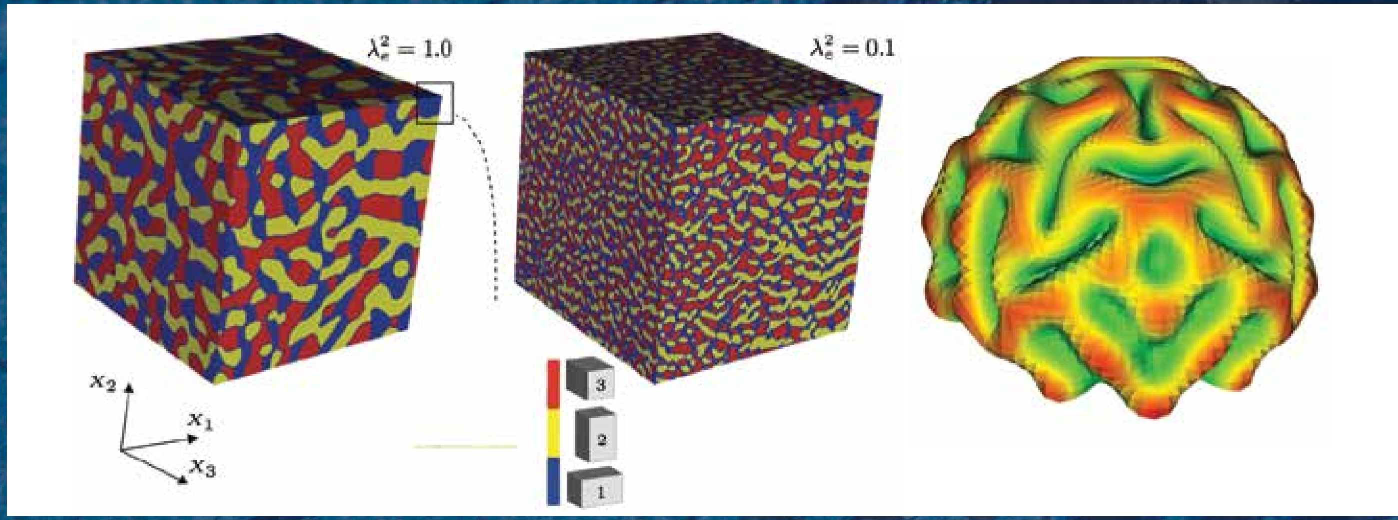
Scientist and mathematician Alan Turing's reaction-diffusion equations describe many patterning phenomena, and some mass transport equations do, too. More recently, biophysicists are recognizing that physical forces, governed by nonlinear elasticity, also play key roles in determining size and positioning.

In an article published in the *Journal of the Mechanics and Physics of Solids* in 2017, Garikipati presented an overview of the partial differential equations that govern patterning and morphogenesis observed by developmental biologists.

He notes that research into the two phenomena of patterning and morphogenesis has taken place, to a great extent, independently of one other. The theoretical frameworks he has developed, by contrast, attempt to bridge the physical processes by focusing on the corresponding equation systems.

Theoretical frameworks in hand, Garikipati works closely with biologists to take these mathematical and physical descriptions and apply the equations developed to a range of questions, including how villi form in the small intestine and how the folded pattern of the brain's cortex is created.





New methods in machine learning will help use big data to improve our capability to model and predict physics.

"That foldedness serves a neurological purpose; it's not just a curiosity," Garikipati said. The increased surface area created by the ridges (gyri) and the grooves (sulci) allows neurons to be situated close to each other. As a result, the axons that connect them don't have to build as lengthy a path and instead can develop more complex connections.

"If the gyri and sulci don't fold—or buckle, to borrow an elasticity term—like they're supposed to, or they're not the right size or in the right position, developmental abnormalities ensue," Garikipati said. "Bringing mechanics theories to bear helps us better describe how healthy and unhealthy folding occurs."

In related work, published in *Integrative Biology* in 2016, Garikipati and colleagues created a novel predictive computational model describing how tissue forces and signaling events interact to very quickly create the patterns in cell membranes that determine where each villus should be positioned.

While the general role of mechanics had been suspected for a few years, Garikipati's work showed that a particularly intricate choreography of cell multiplication, migration and forces of cell contractility underlies the early stages of villi formation and positioning.

MACHINE LEARNING TO PREDICT PHYSICS

The next step, in both biological and materials systems, is to put the new theoretical models through their paces in an ambitious data-driven computational initiative, which leverages the latest advances in machine learning, or artificial intelligence.

"We've validated our models experimentally, so we know we've incorporated the right physics. Turning to data now will help us fill in some of the details about values and parameters that aren't settled by theory alone," said Garikipati, who also directs the Michigan Institute for Computational Discovery & Engineering. "New methods in machine learning will help use big data to improve our capability to model and predict physics."

Morphology is the study of **form, size, structure** and positioning in living systems

TOP LEFT: During development, cells in the iris and sclera (whites) of the eye sense their positions by the physical principles of mechanics and mass transport.

BOTTOM LEFT: Computations of charge distribution in electrode particles controlled by electrochemistry and mechanics.

TOP RIGHT: Mechanics and chemistry are at play in forming the patterned microstructures in inorganic materials (left). Elastic buckling initiates the characteristic folded appearance of the brain (an idealized model is demonstrated on the right).

Field-Effect Transistors
for Multibit Memory and Biosensing

ME Professor **Xiaogan Liang** runs the U-M Nanoengineering and Nanodevice Laboratory, and his work has focused on a longstanding engineering challenge: how to shrink the size while increasing the power of electronic devices for a wide range of applications.

To overcome the challenge, Liang works with two-dimensional (2D) layered semiconductors, such as molybdenum disulfide (MoS2). In previous work, Liang had found that using plasma to dope MoS2 creates a rippled effect that creates a charge-trapping layer, opening up new avenues for field-effect transistors and relevant nanoelectronic devices that can be used for multibit memory storage, ultrasensitive biosensing and more.

So when graduate student **Mikai Chen**, a PhD candidate in Liang's lab, approached Liang and said he had observed a similar ripped effect without the doping process in a different mechanically-exfoliated 2D material—tungsten diselenide (WSe2)—Liang was intrigued.

"In many ways, the materials are like cousins," he said, "so it wasn't a huge surprise that we would see this ripple pattern. But without doping? I have to admit I was skeptical at first."

Liang and Chen took another look. Using high-resolution transmission electron microscopy, the team observed a moiré pattern in the few-layered material's crystal structure that indicated a particular type of mechanical deformation, interlayer twisting.

In an article published in *ACS Nano* in 2017, Liang and his group describe their investigation into the charge-trapping properties of the WSe2 flakes that were mechanically exfoliated from the bulk material using a stamping technique Liang previously developed.

By applying electrical pulses of varying magnitudes, the team was able to create multiple charge-trapping states in the flakes without doping. They also showed that calibrating the excited charge trapping states of several FETs can lead to long-term multibit storage devices.

Liang and his group hypothesized that the interlayer twisting they observed resulted from the mechanical exfoliation process, and their surface and other characterization methods in fact showed that to be the case.

"This brings us another step closer to a deeper understanding of how charge trapping works in these emerging materials," said Liang. "They have so much potential, and it's exciting to think about the applications."

How to **shrink the size** while **increasing the power** of electronic devices.

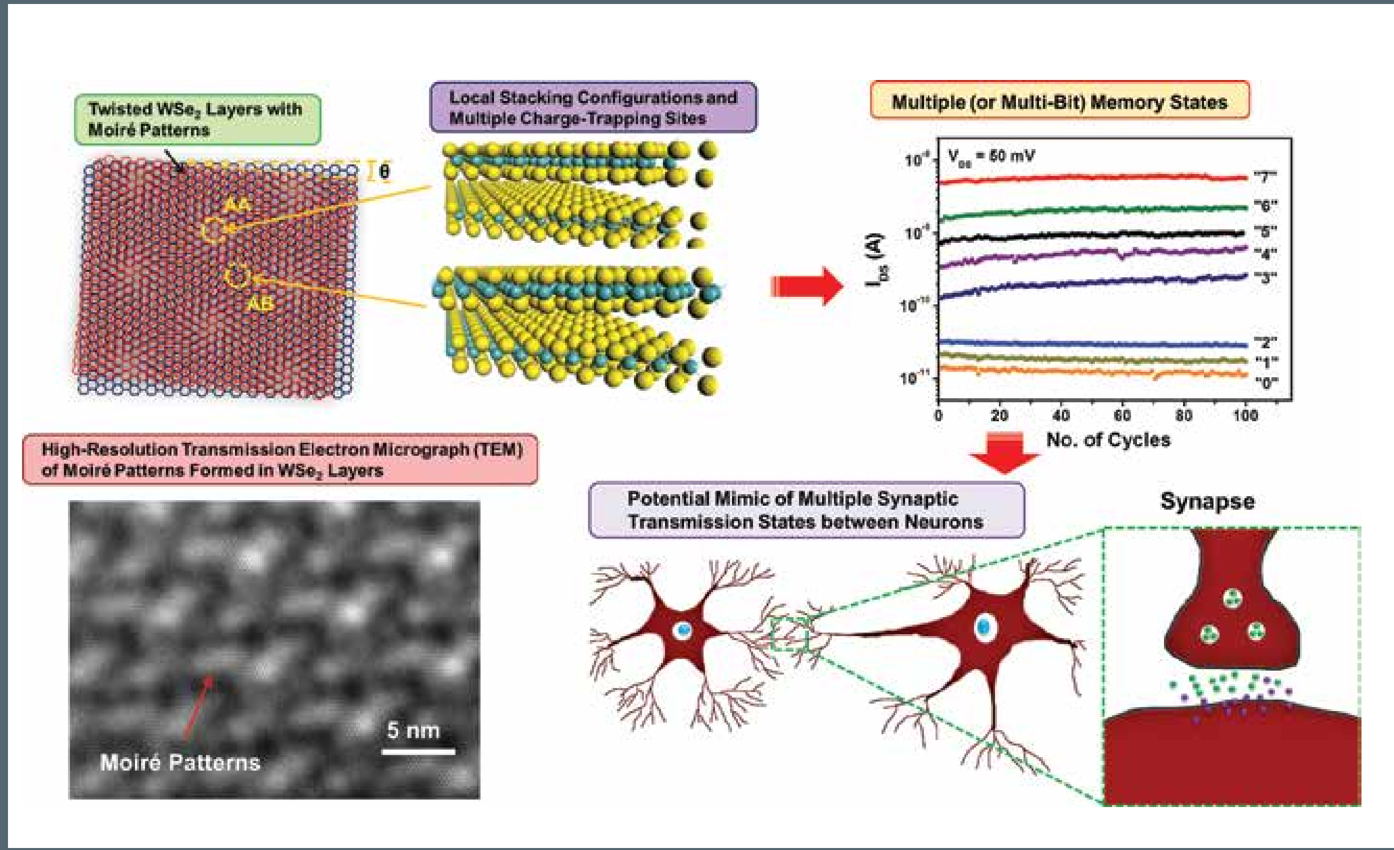
BEYOND BINARY CONFIGURATIONS

One application area Liang is particularly enthusiastic about is functional neuromorphics, in which electronic circuits mimic how mammalian nerve cells work. In particular, Liang is looking at control functionality for next-generation aircraft, whose wings might learn to move in much the same way as baby birds learn to fly.

"The computing capabilities we have today aren't enough for applications like this," said Liang. "For this, we need electronic circuits with multiple excitation sites, which these materials provide. It's like artificial intelligence at the hardware, rather than software, level."

And it's one of the grand challenges posed by the National Academy of Engineering—developing electronic devices that go beyond the existing CMOS, or binary, configuration to those that replicate how neurons work.

"Functional neuromorphic devices may very well represent an entirely new generation of solutions in a post-CMOS age," Liang said.



TOP LEFT: Illustration of Moiré patterns formed by twisted 2D layers. BOTTOM LEFT: High-resolution transmission electron micrograph of real Moiré patterns. TOP RIGHT: Multiple memory states excited in one of Liang's 2D layered devices. BOTTOM RIGHT: Illustration of the potential mimic of multiple synaptic transmission states in a neuromorphic system.

BUILDING BETTER BIOSENSORS

The FETs made from the 2D materials Liang works with have also been shown to be highly sensitive and selective biosensors with performance that exceeds other types of sensors including optical, thermal and mechanical. But for most applications, the FET sensors must withstand being in solution. Since solutions are conductive, ions can interact with the electronic device, producing noise and a screening effect.

"Ions can block the electric field from the charge on the target molecules, so the sensing device may not detect the charge or generate a signal," Liang explained.

In addition, voltage must be applied for the sensor to function. In the absence of an isolating material that separates the electrode from the solution, significant leakage can occur in less time than some types of detection require.

"Wet conditions simply haven't been compatible with these sensors," Liang said.

Until Liang developed a new method, that is. In work published in *ACS Sensors* in 2017, he and his group demonstrated a novel four-stage approach: incubation, flushing, drying and measurement. In summary, the MoS2 sensor is briefly exposed to the target material, then the analyte is flushed away and the sensor is dried before the electronic measurements are taken.

> This brings us another step closer to a deeper understanding of how charge trapping works in these emerging materials.

"In this way, we can realize the real-time quantification of biomarkers with high sensitivity and selectivity without the usual damage from the solution or screening effects," Liang said.

His group has collaborated with ME Professor **Katsuo Kurabayashi** and demonstrated the method with complex clinical solutions such as saliva, quantifying interleukin-1 beta down to approximately one femtomolar in less than 30 minutes.

The next step is to integrate the sensors and methodology into clinical settings and explore new clinical applications related to inflammatory diseases, traumatic brain injuries and organ transplantation.

Puzzling Out a Giant Rubik's Cube

Students Unveil Working Device in Capstone Design Class

A giant Rubik's Cube newly installed on the University of Michigan's North Campus is believed to be one of the world's largest hand-solvable, stationary versions of the famous puzzle.

The 1,500-pound, mostly aluminum apparatus was unveiled April 14, 2017 on the southwest corner of the second floor of the GG Brown Building. It was imagined, designed and built by two teams of mechanical engineering undergraduate students over the course of three years as part of an ME450 project.

"Now North Campus has an iconic cube of our own," said mechanical engineering student and cube co-developer **Ryan Kuhn**, referring to the spinning Tony Rosenthal sculpture on U-M's central campus.

The colorful, new cube is meant to be touched and solved. The students worked hard to figure out a movement mechanism that would enable that. They realized they couldn't simply scale up the approach a handheld cube relies on because the friction would be too great. So to keep friction minimal, they devised a setup that utilizes rollers and transfer bearings.

"This is a truly amazing and unique kinematic mechanism that functions as a Rubik's cube. The students have successfully designed and built this massive Rubik's cube as a work of functional art for our campus," said **Noel Perkins**, the Donald T. Greenwood Collegiate Professor of Mechanical Engineering and advisor to the students.

The first group of students came up with the idea for the cube on Pi Day, 2014. **Martin Harris**, who can solve one in 43 seconds, and **Samuelina Wright**, who can deconstruct one and reassemble it in a solved state, were hanging out in the College of Engineering honors office. Harris was fiddling with his cube when Wright had a vision: What if they made a massive version as a nod to the Central Campus sculpture?

The two got approval to carry the idea forward as a capstone senior design project.

The first team of four students—**Kelsey Hockstad**, **Dan Hiemstra**, Harris and Wright—worked on it for two years and graduated in 2016. The cube still needed fine tuning, as well as a stand. They convinced another cohort—**Jason Hoving**, **Ryan Kuhn** and **Doug Nordman**—to continue the project. The original team stayed involved to guide them.

Harris, who currently works as an as an engineer for Herman Miller in Holland, Michigan, has been intrigued with Rubik's cubes since childhood.

"The Rubik's cube has been a consistent source of relaxation and mystery for me over the years, which is what I love most about it," he said. "Since high school I have thought of it as a physical representation of entropy. By inputting enough work, it's possible to make the cube more organized, but its natural tendency is toward chaos."

Since it was invented in 1974, the Rubik's cube has become the world's best-selling puzzle game—one that introduced and promoted mathematical thinking to generations. Solving it involves recognizing patterns and developing and implementing algorithms.

The large version on North Campus requires more than that: fatigue, ergonomics and even harmonics become part of the design picture, Harris said. So does collaboration.

"The point of making a Rubik's cube so large was primarily to introduce teamwork to the puzzle solving process," Harris said. "Real-world problems can rarely be solved without the cooperation of several different people. It's a simple idea, but one that is crucial to science, technology, engineering and math fields."

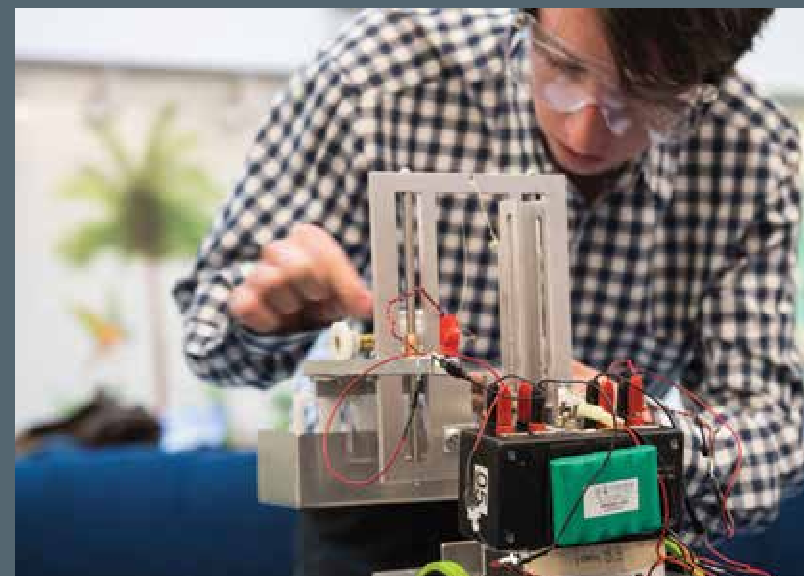
The cube isn't just about STEM fields.

"The project," said Wright, who now works as an engineer at Boeing, "became a fusion of both art and engineering, much like North Campus, the cube's home."

Interested in checking out U-M ME's massive Rubik's Cube for yourself? Visit https://me.engin.umich.edu and click on the "Events" calendar for the latest Rubik's Cube hosted visiting hours.

STORY BY: Kelly O'Sullivan, Michigan Engineering
PHOTOS: Joseph Xu, Michigan Engineering

MEUS a Growing Success



The fifth annual ME Undergraduate Symposium (MEUS) was held this past April where 35 individual research projects were presented along with more than 450 design team projects. The event provides a venue for ME's undergraduate students to showcase their projects for RISE (Research, Innovation, Service and Entrepreneurship) as well as their Design and Manufacturing X50 Courses.

Since its inception in 2015, the event has used feedback from students and attendees to help shape future symposia; additions include a variety of workshops as well as a best poster, best paper and best session awards.

The next MEUS is scheduled for December 7, 2017. For more details about MEUS visit meus.engin.umich.edu. For more information on RISE, visit me.engin.umich.edu/academics/rise.

ME's Career Week Gaining Momentum

U-M ME held its second annual Career Week this past spring. The event, which took place March 20–24, helped students in early career exploration determine whether their interests lie in academia or industry within the field of mechanical engineering. With more than 50 student participants, Career Week featured events for both undergraduate and graduate students, including workshops geared toward successful resume building and talks with representatives from industries such as automotive, energy and manufacturing. The next Career Week is scheduled for November 13-17, 2017.

Shining New Thing

The University of Michigan Solar Car Team crossed the finish line of the 2016 American Solar Challenge (ASC) in first place—a record-breaking 11 hours ahead of the second-place team. The win represents the team's sixth consecutive, and ninth overall, victory.

And now the team has built its newest and most innovative vehicle yet.

"In our last build cycle, we completely redesigned our car from the ground up," said **Vignesh Jagathese**, a rising sophomore and interim operations director. "Our new car, *Novum*, is significantly faster and more efficient than our last vehicle *Aurum*, and represents a new direction for the team."

The redesign was driven by two key factors: newer technology in the form of multi-junction gallium arsenide solar cells that offer about a 15 percent improvement in solar efficiency, and a WSC rules change.

"The change in regulations for the race opened up a lot of possibilities in terms of design, including increased dimensions for the car and decreased dimensions for the array," said **Andrew Toennies** (BSE ME 2019), interim engineering director.

The team stretched the length of the car to five meters to fit a narrower array of panels. With the solar cells' improved efficiency, the team was able to fit an array less than half the area of *Aurum*'s on a body 43 percent narrower than *Aurum*—while taking in enough power to sustain a similar speed, about 50 to 55 mph, Toennies added.

The narrower car body, about a meter in width, necessitated other design changes—and no small measure of creativity. The team transitioned to a single-fairing design, in which the vehicle's components are packaged in a single aerodynamic shell, from *Aurum*'s—and other previous vehicles'—dual-fairing style.

Simulations estimate that *Novum* will be about 20 percent more efficient than *Aurum*, the only vehicle in the 2016 ASC to complete the race using 100 percent solar power.

The team owes its consistent success to careful documentation, knowledge transfer and dedicated alumni. "We rely on those who have been in our shoes before, and we work from documents and procedures detailing how they succeeded," said Jagathese. Alumni are invited to design reviews to critique progress and consult on the current state of the team, he added.

Hardly resting on laurels, the team continues to refine *Novum* as it prepares to cross the Australian outback in the 1,800-mile, eight-day Bridgestone World Solar Challenge in October 2017.

Given the significant changes *Novum* boasts, ongoing testing is crucial. "It's hard to build a solar car that performs okay; it's even harder to build a solar that performs at a world-class level," said Toennies. "The extensive testing our team performs not only points out opportunities for improving our design, it also prepares us to race a solar car—pit stops operations, regimented efficiency and transportation logistics, including the large caravan that travels with the solar car. As a result, we have to stick to our schedules, even if it means a few late nights in the process."

Another takeaway from the most recent design cycle, according to Toennies, "is never to write off any ideas as too crazy—without those so-called crazy ideas, we wouldn't have ended up with *Novum*."

To keep the flow of ideas strong, the team is focused on recruiting new members. It's also one of the University's first teams to develop a diversity, equity and inclusion (DEI) plan.

"We're placing a stronger focus on DEI because of its important role in improving the University, the College of Engineering and our team," said **Abby Siegal**, a rising junior and the team's interim business director.

Once the WSC is behind the U-M Solar Car Team in October, it will look ahead with one shared goal: winning the 2018 American Solar Challenge.

MRacing knows
the formula for success

MRacing, U-M's Formula SAE® series team, finished its racing season in the number two spot among U.S. teams.

The team owes its strong season, in large part, to several design improvements to last year's vehicle. According to team captain **Martin McCann** (BSM ME 2019), a carbon fiber composite chassis and modifications to other systems lightened vehicle weight to an impressive 430 pounds; the addition of a turbocharger boosted the powertrain system; and the redesigned aerodynamics package increased downforce to improve speed in cornering.

All told, these and other changes led to a fifth-place finish at Formula SAE Michigan, the four-day competition held in May at the Michigan International Speedway (MIS). That finish, with an average lap time of 1:08 minutes, led to a number two ranking among 120 U.S. teams.

At the Formula North competition in Ontario, Canada, in June the team placed first overall, with first-place finishes in both the acceleration event and the 22-kilometer endurance race.

McCann credits the winning results with the team's nose-to-the-grindstone approach, which allowed it to finish the car earlier than ever before.

"We're extremely proud of the work our members put in consistently throughout the year, including some late nights working in the shop. It meant the testing crew was able to run the car almost every weekend since the car's completion," he said.

Improved time management was a team focus this year, too. "Instead of distributing the workload of a race season evenly across the various systems of the car," McCann said, "we chose to focus our limited time and resources on the most critical issues we experienced in 2016. By investigating what's best for the whole car versus individual components, we produced a more reliable car in less time."

Outreach was another large part of the season. In addition to displaying the vehicle at the Detroit International Auto Show and participating in the Woodward Dream Cruise, the team hosted preschool students from the Towsley Children's House at its North Campus shop to teach them about race cars. The kids, not surprisingly, loved the experience—sitting in the car and peppering team members with questions.

Next stop is Barcelona, where MRacing will compete in Formula Student Spain as the only American team. "With the tuning of our new powertrain and extensive training of our drivers over the summer, we've dropped significant time and should pose a real threat in Spain," McCann said.

Looking at the road—and the season—ahead, the team's goal is to take the number-one spot as the best North American Formula SAE team. The top-ranked team, Oregon State's Global Formula Racing, has held a top-five spot for several years. And, McCann added, "we're also hoping to continue to hold onto our championship belt from the Formula North competition in Canada."

When the going gets rough
Michigan Baja sets records

The U-M Baja SAE® off-road team had anything but a rocky season. For the third consecutive year—and the first time in the history of the Baja SAE series—the team claimed the Mike Schmidt Memorial Iron Team Award. The award is given to the team earning the highest number of cumulative points during the racing season, making it in effect the national championship of Baja SAE.

Michigan Baja got off to a strong start at its first competition in California in April, placing in the top three in several static and dynamic events, including first place in sales, acceleration, maneuverability and suspension and traction and overall dynamics.

But about 60 minutes into the four-hour endurance race, the car ahead of the Michigan team's vehicle nose-dived over a jump, according to team captain **Alex Gardner** (BSE ME 2018). The other car rolled backward onto the team's car, collapsing part of the front frame. Unable to stop in time, two trailing cars landed on top of the rear frame, which damaged the rear suspension.

"That no one was hurt was a testament to the safety features installed in the cars," Gardner said, but the repairs required a new rear suspension and welding, which took the team out of the race for over 90 minutes.

Despite that, the team finished second overall. "We were even more motivated to succeed in the final two competitions in order to claim the Mike Schmidt award," Gardner added.

At the second competition, held in Kansas in May, the team finished first overall, as well as first in acceleration, maneuverability, suspension and traction.

At the third competition in Illinois, Michigan Baja took third place overall, with second place finishes in design, acceleration, hill climb and endurance.

Gardner credits a completely redesigned vehicle for the team's winning performances. To increase driveline efficiencies and improve handling, members used an H-Arm design rather than the previous trailing link, which improved the motion ratio and handling. The change also lightened the rear suspension weight since the new design could be made of aluminum instead of steel.

In addition, improvements were made to the Ackermann geometry, caster and kingpin inclination in the front suspension to increase tire grip potential, reduce the turning radius and also improve handling.

Lightweight aluminum center gears both reduced mass and the moment of inertia in the driveline. Additional changes in the mechanical design of the continuously variable transmission further lowered the moment of inertia by 20 percent.

While vehicle performance was critical, team dynamics played no less a role. "One of the things that led to our great success on the track was how well everyone worked together all year," Gardner said. "We spent a lot of time grinding away in the shop, but we were able to make a lot of fun of all the work and formed some great friendships."

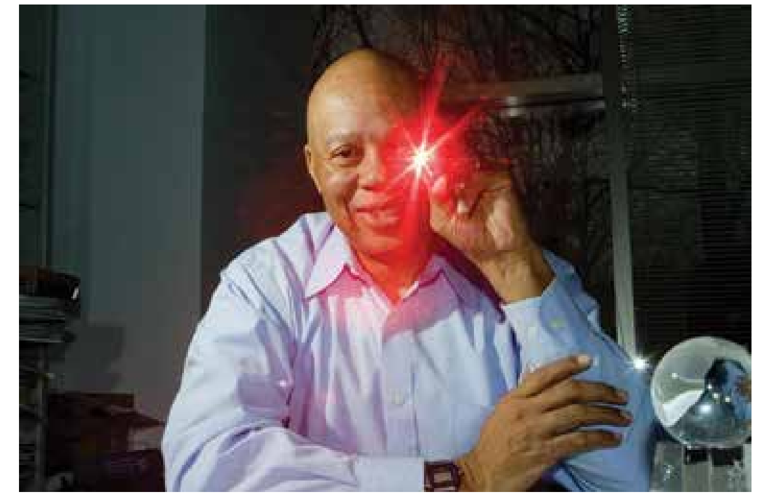
A shared vision is motivating the team for the coming year. "First and foremost, the team's goal is to claim the Mike Schmidt Memorial Iron Team Award for a fourth year in a row. We all want to set the bar higher again this year," Gardner said. "We'll have to work harder than ever to keep innovating, but everyone on the team has their eye on the same prize."

Videos of the Baja SAE events are available from the team's Facebook page: https://www.facebook.com/michiganbajaracing

U-M ME GEARS UP TO CELEBRATE 150 YEARS

In 2018, one year after the University of Michigan observes its 200th anniversary, the U-M Department of Mechanical Engineering will mark a major milestone of its own as it celebrates its 150th. The U-M program helped pioneer the field 150 years ago, and continues to be a worldwide leader in research and education, both basic and translational, from automotive engineering to energy to bio/health and beyond.

The ME Department has a series of educational and fun events scheduled for September 21 and 22, 2018. For a detailed schedule of events and more information on how you can get involved and help us celebrate this historic event, visit: me.engin.umich.edu/me150.



Laser Pioneer Marshall Jones (BSE ME ’65) Joins the Inventors Hall of Fame

Marshall Jones was inducted May 4th, 2017, into the National Inventors Hall of Fame in Washington DC for his pioneering work with industrial lasers.

There are only 547 members of the Hall—only about 100 of whom are still living—out of an estimated 2 million engineers working in America today.

Since 1974, Jones has worked for GE Global Research, where he currently serves as principal engineer in Manufacturing & Materials Technologies.

Chen Honored with 2017 Alumni Merit Award

Mechanical Engineering alumnus **Yudong Chen** has been selected to receive the 2016 U-M ME Alumni Merit Award. Chen (MSE ME, PhD ’91) is currently president of Bosch (China) Investment Ltd. He has served as US-NSF-STA Research Fellow at the Japan Science and Technology Agency, where he served as a consultant for Japanese researchers and industries on concurrent manufacturing systems, and on FMS for the automotive industry. Chen joined the Bosch Group Gasoline Engine Department as the Senior Vice President responsible for business development in China.

Chen was Executive Vice President in charge of Original Equipment Sales for Bosch (China) Investment Ltd. from 2008 to 2010. In 2011, he went on to serve as the President of Bosch (China) Investment Ltd., a role he remains in today.

Remembering Bruce Karnopp

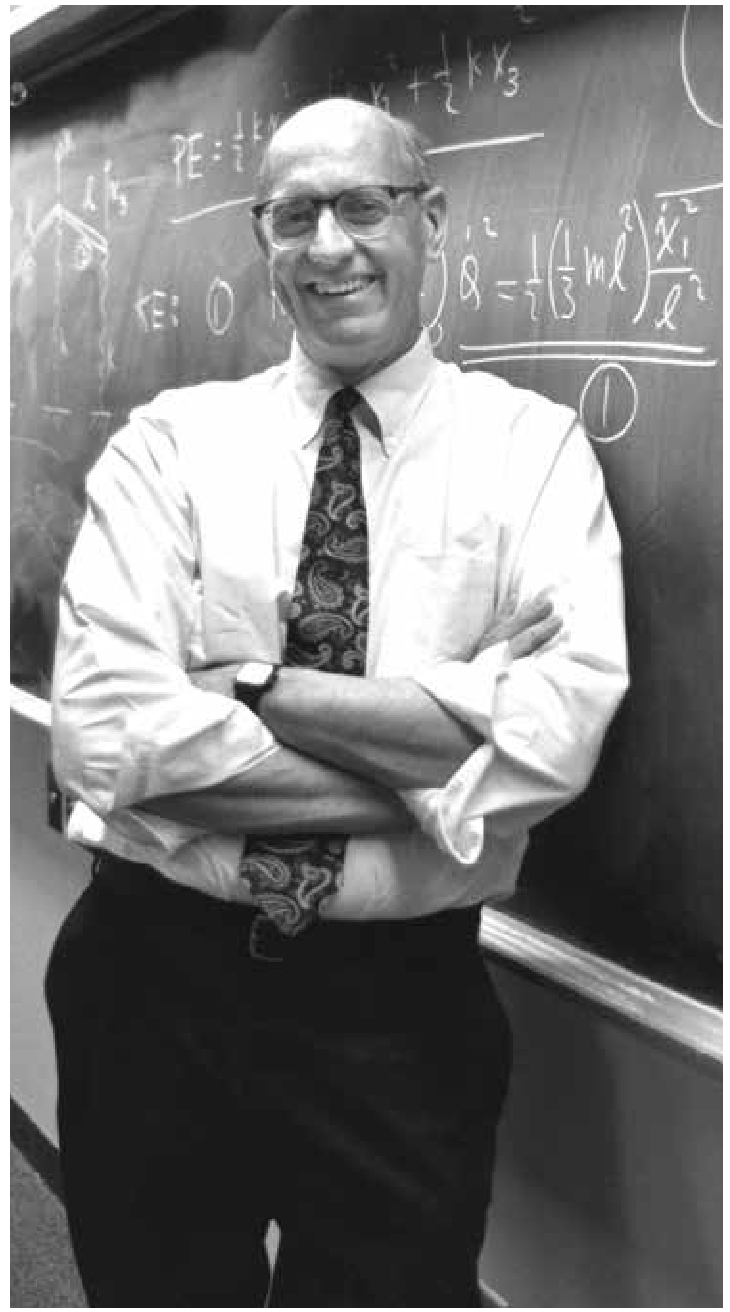
U-M and ME Associate Professor Emeritus Bruce H. Karnopp, PhD, passed away on January 1, 2017. Karnopp spent nearly four decades teaching at U-M ME before retiring in May of 2004.

Well known in the field of dynamics, Karnopp's vast knowledge on the subject made him a one-of-a-kind educator. In fact, his reputation as an instructor at U-M ME has been described as legendary. Throughout the course of his 36-year career, Karnopp's teaching impacted the lives of more than 15,000 students, many of whom described him as the best instructor they'd ever had at the University of Michigan. His passion and talents earned him numerous accolades throughout his teaching career, including the Amoco Foundation Faculty Teaching Award, the Arthur F. Thurnau Professorship, the College of Engineering (CoE) Teaching Excellence Award, and the Michigan Association of Governing Boards of State Universities Distinguished Faculty Award. He was also selected as "Professor of the Term" six times by the University of Michigan Chapter of Pi Tau Sigma and served as faculty advisor to the 1993 National Champion Sunrayce Solar Car team.

Awards and accolades aren't the only things Professor Karnopp will be remembered for. While serving as an assistant dean for the U-M College of Engineering from 1984 to 1989, he initiated recruiting programs for under-represented minorities and out-of-state students. He also spearheaded a project to improve access to the University for students in rural areas of Michigan. Karnopp served as the chair of U-M's Admissions Advisory Committee, where he helped to develop the mission statement that articulates the University's longstanding commitment to diversity. He participated in U-M CoE's Summer Engineering Academy, preparing new students for success at the University. And, during his 13 years of service in the U-M CoE Orientation Program, he was often the first face seen by the incoming class of students and their parents.

Karnopp's charisma and love for teaching was a gift to the U-M CoE's and the students he touched. He will be sorely missed by all!

Donations in Professor Bruce Karnopp's memory are being accepted for the Brain Bank Discovery Fund. Checks may be made to "University of Michigan" and sent to Medical Development, 1000 Oakbrook, Suite 100, Ann Arbor, MI 48104.



Faculty Awards & Recognition

EXTERNAL AWARDS

ELLEN ARRUDA
National Academy of Engineering, 2017

JAMES ASHTON-MILLER
ORS/AAOS Kappa Delta Award, 2016

ARVIND ATREYA
SFPE Arthur B. Guise Medal, 2017

SHORYA AWTAR
ASME Best Conference Paper on Mechatronics Award, 2017

JIM BARBER
ASME Mayo D. Hersey Award, 2017

KIRA BARTON
ASME Dynamic Systems and Control Division Young Investigator Award, 2017

SAM DALY
SEM James W. Dally Young Investigator Award, 2016

NEIL DASGUPTA
AFOSR Young Investigator Research Program Award, 2016
American Vacuum Society (AVS) Paul Holloway Young Investigator Award, 2016
3M Non-Tenured Faculty Award, 2017
SME Yoram Koren Outstanding Young Manufacturing Engineer Award, 2017

JACK HU
SME Gold Medal, 2017

XIAONING JIN
SME Outstanding Young Manufacturing Engineer, 2016

NOBORU KIKUCHI
National Academy of Engineering, 2017

YORAM KOREN
SME Yoram Koren Outstanding Young Manufacturing Engineer Award (Namesake), 2017

JYOTI MAZUMDER
ASME/SME Eugene Merchant Manufacturing Medal, 2017

CHINEDUM OKWUDIRE
SAE Ralph R. Teetor Educational Award, 2016
SME Outstanding Young Manufacturing Engineer, 2016
Young Investigator Award, International Symposium on Flexible Automation, 2016
ASME Best Conference Paper on Mechatronics Award, 2017

JWO PAN
SAE Medal of Honor, 2017

HUEI PENG
ASME Dynamic Systems and Control Division - Michael J. Rabins Leadership Award, 2017

JASON SIEGEL
IEEE Control Systems Technology Award, 2017

TRAVIS THOMPSON
Forbes' "30 Under 30" for Energy (*Forbes* Magazine's top energy tech entrepreneurs under the age of 30), 2017

DAWN TILBURY
Engineering Society of Detroit (ESD) Gold Award, 2016

ANNA STEFANOPOULOU
IEEE Control Systems Technology Award, 2017

GALIP ULSOY
ASME Rudolf Kalman Best Paper Award, 2017

ANGELA VIOLI
Adel Sarofim Award, 2017

KON-WELL WANG
ASME Adaptive Structures & Material Systems Best Paper Award, 2016
ASME J.P. Den Hartog Award, 2017

U-M AWARDS

ELLEN ARRUDA
The Maria Comninou Collegiate Professorship, 2017

SHORYA AWTAR
Rexford E. Hall Innovation Excellence Award, 2017

MIKI BANU
Kenneth M. Reese Outstanding Research Scientist, 2017

KIRA BARTON
ME Department Achievement Award, 2016
Miller Faculty Scholar, 2017

STANI BOHAC
CoE Kenneth M. Reese Outstanding Research Scientist Award, 2016

STEVE CECCIO
Vincent T. and Gloria M. Gorguze Professorship, 2016

BOGDAN EPUREANU
CoE John F. Ullrich Education Excellence Award, 2016

TULGA ERSAL
UMOR Research Faculty Recognition Award, 2016

ERIC JOHNSEN
ME Department Achievement Award, 2017

SRIDHAR KOTA
Distinguished University Innovator Award, 2017

XIAOGAN LIANG
CoE 1938E Award, 2016

WEI LU
Ted Kennedy Family Faculty Team Excellence Award, 2017

CHINEDUM OKWUDIRE
ME Department Achievement Award, 2017
Martin Luther King Spirit Award, 2017

HUEI PENG
Roger L. McCarthy Professorship, 2016

DON SIEGEL
ME Department Achievement Award, 2016

KATHLEEN SIENKO
Arthur F. Thurnau Professorship, 2016

STEVEN SKERLOS
CoE Trudy Huebner Service Excellence Award, 2016

ANNA STEFANOPOULOU
William Clay Ford Professorship, 2017

MICHAEL THOULESS
Janine Johnson Weins Professorship, 2016
Ted Kennedy Family Faculty Team Excellence Award, 2017

MARGARET WOOLDRIDGE
CoE David E. Liddle Research Excellence Award, 2016
Neil Van Eenam Memorial Undergraduate Teaching Award, 2017
Digital Education and Innovation Academic Innovation Fellow, 2016

Student Awards

GRADUATE STUDENT AWARDS

DANIEL KEANE BRUDER
National Science Foundation Graduate Research Fellowship Program, 2017

LEQING CUI
ASME Best Conference Paper on Mechatronics Award, 2017

LONGJI CUI
Caddell Team Award for Research (Edgar Meyhofer & Pramod Sangi Reddy, Faculty, 2016)
Alexander Azarkhin Fellowship, 2016

SAMBIT DAS
Michigan Institute for Computational Discovery and Engineering Fellowship, 2016
J. Robert Beyster Computational Innovation Graduate Fellowship, 2017

MARC HENRY DE FRAHAN
Rackham PreDoctoral Fellowship, 2016
CoE Richard F. and Eleanor A. Towner Prize for Distinguished Academic Achievement, 2016

ANDREW LAIRD DAVIS
National Science Foundation Graduate Research Fellowship Program, 2017

MIRIAM FIGUEROA-SANTOS
National Science Foundation Graduate Research Fellowship Program, 2016

ANTHONY FIORINO
Caddell Team Award for Research (Edgar Meyhofer & Pramod Sangi Reddy, Faculty, 2016)

TYLER FLYNN
National Defense Science and Engineering Graduate (NDSEG) Fellowship, 2016

HAOWEN GE
CoE Distinguished Achievement Award, 2016
William Mirsky Memorial Fellowship, 2017
Rackham Summer Award, 2017

NEIL GOPAL SYAL
J.A. Bursley Mechanical Engineering Award, 2016

KEVIN GREEN
National Science Foundation Graduate Research Fellowship Program, 2017

ALISON HAKE
National Science Foundation Graduate Research Fellowship Program, 2016

MICHELLE HARR
National Science Foundation Graduate Research Fellowship Program, 2016

MEGAN HATHCOCK
National Science Foundation Graduate Research Fellowship Program, 2017

JOHANNA HEUREAUX
STAR Society of Hispanic Professional Engineers Technical Achievement Recognition Award, 2017

KENNETH HO
Ivor K. McIvor Memorial Award, 2017

KIMBERLY INGRAHAM
National Science Foundation Graduate Research Fellowship Program, 2016

ASHWIN KANNAN IYENGAR
Rackham Summer Award, 2017

AMAN KUMAR JHA
Rackham Summer Award, 2017

DEVYANI KALVIT
Rackham Summer Award, 2016

SAEED KAZEMIABNAVI
Richard F. and Eleanor A. Towner Prize For Distinguished Academic Achievement, 2017

ILYA KOVALENKO
National Science Foundation Graduate Research Fellowship Program, 2016

NAN LI
William Mirsky Memorial Fellowship, 2016

ZIDA LI
Baxter Young Investigator Award, 2016

LIXI LIU
National Science Foundation Graduate Research Fellowship Program, 2016

BRYAN MALDONADO
Rackham Summer Award, 2016

EVA MUNGAI
National Science Foundation Graduate Research Fellowship Program, 2017

LAURA MURPHY
CoE Harry B. Benford Award for Entrepreneurial Leadership, 2016

VAHID RASHIDI
CoE Distinguished Leadership Award, 2016

AGNES RESTO
National Science Foundation Graduate Research Fellowship Program, 2017

MAURO RODRIGUEZ
Rackham Predoctoral Fellowship, 2017
Ford Foundation Dissertation Fellowship, 2017

RYAN ANTHONY ROSARIO
National Science Foundation Graduate Research Fellowship Program, 2017

JACOB RYNEARSON
Rackham Summer Award, 2017

ADRIAN JAVIER SANCHEZ
National Science Foundation Graduate Research Fellowship Program, 2017

ARITRA SASMAL
Alexander Azarkhin Fellowship, 2017

RACHEL SCHWIND
U.S. Department of Energy Office of Science Graduate Research Award, 2017

GREGORY STEVEN SHALLCROSS
National Science Foundation Graduate Research Fellowship Program, 2017
NASA Space Technology Research Fellowship, 2017

YUE SHAO
Richard F. and Eleanor A. Towner Prize for Outstanding PhD Research, 2017

BAI SONG
Caddell Team Award for Research (Edgar Meyhofer & Pramod Sangi Reddy, Faculty, 2016)

ANDREW STEPHENS
National Science Foundation Graduate Research Fellowship, 2016

SHIN-JANG SUNG
Caddell Team Award for Research (Jwo Pan, Faculty, 2017)

SARAH VERNER
Michigan Institute for Computational Discovery and Engineering Fellowship, 2016
National Science Foundation Graduate Research Fellowship Program, 2016

KEVIN WELD
William Mirsky Memorial Fellowship, 2016

SHINUO WENG
Ivor K. McIvor Memorial Award, 2016

SHENGJIA WU
William Mirsky Memorial Fellowship, 2017

PETER YAO
Rackham Summer Award, 2017

VINIT KUMAR ZAREEF
Rackham Summer Award, 2017

CHUMING ZHAO
Rackham Summer Award, 2017

YUQING ZHOU
Michigan Institute for Computational Discovery and Engineering Fellowship, 2016

UNDERGRADUATE STUDENT AWARDS

ALEXANDRA ANDERSON
R&B Tool Scholarship, 2016

CARLOS BARAJAS
National Science Foundation Graduate Research Fellowship Program, 2016
ME Spirit Award, 2016

ARIANNA CARLEY
CoE Harry B. Benford Award for Entrepreneurial Leadership, 2017

JIEXIN CHEN
R&B Tool Scholarship, 2016

LONG KIU CHUNG
Tau Beta Pi First Year Award, 2017

ANNA CROUCH
Rackham Summer Award, 2016

T.J. FLYNN
National Defense Science and Engineering Graduate Fellowship, 2016

MADELINE GILLERAN
ME Spirit Award, 2016

NATHANIEL JOHNSON
COE Distinguished Achievement Award, 2016
Lloyd H. Donnell Scholarship, 2016

JASON KERTAYASA
Caddell Memorial Scholarship, 2016

YOONSEOB KIM
Ivor K. McIvor Memorial Award, 2016

EAMON KUMMERT
Caddell Memorial Scholarship, 2016

JESSICA LIPA
Donnell Scholarship, 2016
MEUS Best Paper Award (David Dowling, Faculty, 2017)

BENNET MCGLADE
R&B Tool Scholarship, 2016

BLAISE NUGENT
R&B Tool Scholarship, 2016

AUDREY OOSTERWAL
ME Spirit Award, 2016

DEMI OUTMAN
ME Spirit Award, 2016

YATRI PATEL
R&B Tool Scholarship, 2016

LINDSAY FRASER PURVIS
Caddell Memorial Scholarship, 2016

PATRICK RANSFORD
Caddell Memorial Scholarship, 2016

MENGYAO RUAN
Caddell Memorial Scholarship, 2016

CAL SALISBURY
R&B Tool Scholarship, 2016

ANDREW STEPHENS
NSF Graduate Research Fellowship, 2016

QIANYU SUN
Caddell Memorial Scholarship, 2016

CLARK TEEPLE
RISE Best Paper Award, (Kenn Oldham, Faculty, 2016)

GABRIELLE VUYLSTEKE
J.A. Bursley Mechanical Engineering Award, 2016

MATTHEW WALDMANN
R&B Tool Scholarship, 2016

EZINWO WELI
ME Spirit Award, 2016

TONG XIE
R&B Tool Scholarship, 2016

WILLIAM YANG
MEUS Best Paper Award (C. David Remy, Faculty, 2017)

GABRIELLE ZACKS
R&B Tool Scholarship, 2016

WENXUAN ZHOU
R&B Tool Scholarship, 2016

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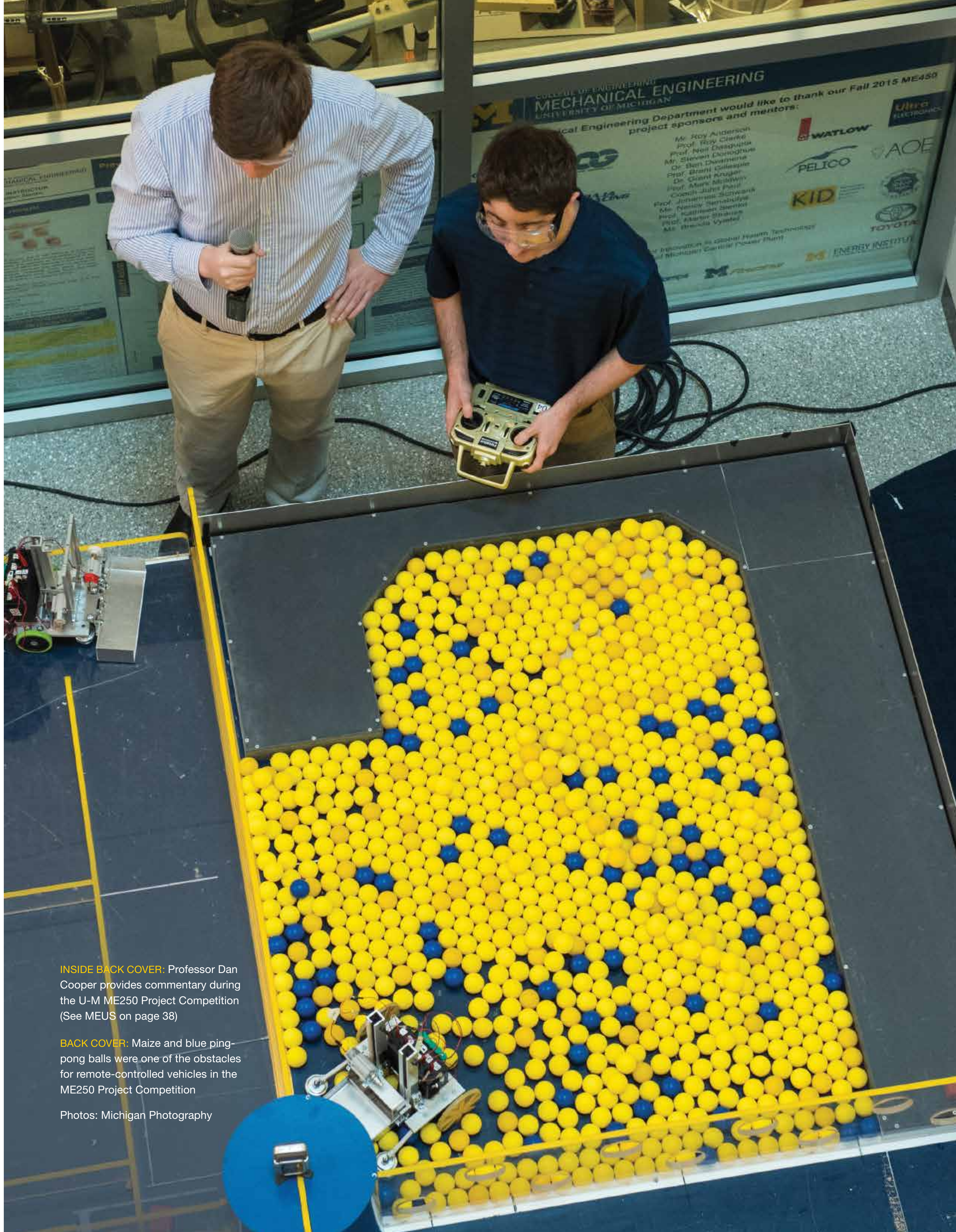

INSIDE BACK COVER: Professor Dan Cooper provides commentary during the U-M ME250 Project Competition (See MEUS on page 38)

BACK COVER: Maize and blue ping-pong balls were one of the obstacles for remote-controlled vehicles in the ME250 Project Competition

Photos: Michigan Photography

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