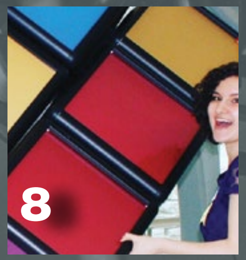
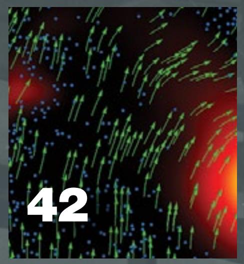
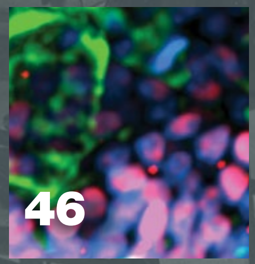
COLLEGE OF ENGINEERING
MECHANICAL ENGINEERING
UNIVERSITY OF MICHIGAN

2017–2018 ANNUAL REPORT

SPECIAL SECTION 150 YEARS IN REVIEW







Contents

Mechanical Engineering Annual Report 2017–2018

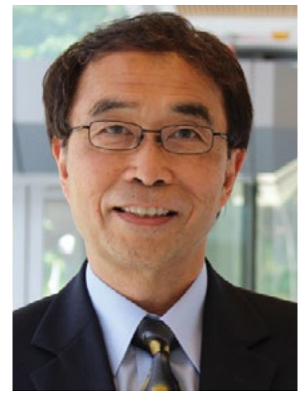
ON THE COVER: A collage of images reflecting the 'Share Your Stories' campaign, as well as historical images courtesy of Bentley Historical Library.

INSIDE SPREAD: An 1894 blacksmithing and machine tool shop which included its own power plant and line shafts powering the belt-driven machines.

Photos: Michigan Engineering

Message from the Chair

> As we reflect on the past in a special section within this annual report—and at our celebratory events in 2018—we also look to the future with the clarity of vision only a storied and unshakable foundation can provide.



It is a true privilege to write this Chair's message as the University of Michigan (U-M) Department of Mechanical Engineering (ME) reaches a remarkable milestone: its 150th anniversary. As we reflect on the past in a special section within this annual report—and at our celebratory events in 2018—we also look to the future with the clarity of vision only a storied and unshakable foundation can provide.

With 72 tenured and tenure-track faculty; 19 research faculty; 55 staff; over 500 graduate students, including more than 250 PhD students; 800 undergraduates; and a network of over 16,000 living alumni, the ME department is well positioned for sustained advancement and success.

As we mark our 150th year, we also mark another milestone in our history, as longtime faculty member Ellen Arruda, who holds the Maria Comninou Collegiate Professorship in Mechanical Engineering, assumes the role of ME's 18th Department Chair on September 1, 2018. You can read more about Professor Arruda's many outstanding accomplishments in the pages that follow. Suffice it to say, the Department could not be in better hands.

Transitions often lead to reflection, and as I prepare to complete my time as Department Chair after two five-year terms, I find myself thinking about the myriad of changes that have taken place since I started my tenure as Chair in 2008. Many of them involve our world-class facilities. In 2014, we completed a major $46-million project that established a new 63,000-square-foot research complex, guided by a vision of the future of mechanical engineering. This new addition to the ME department is a multi-award-winning facility dedicated to research at the intersection of core ME disciplines and emerging areas, including nano-, micro- and bio-systems. The Department completed a second major building project as well: a $50 million renovation of GG Brown to create a student-centric educational facility. Our aim was to provide collaborative and innovative spaces for our renowned pedagogic paradigm and a welcoming home for our students, and the project achieved that goal—and more. In addition, we renovated the Walter E. Lay Automotive Laboratory, also known as the Lay Auto Lab, to create a more welcoming, productive environment both for occupants and the Auto Lab's many visitors.

Since 2008, we have developed a comprehensive and visionary strategic plan, covering all areas of research, education, faculty, staff, facilities and external relations. Twenty-seven new faculty members have since joined the Department, across the strategic disciplines we have identified, gaining international renown for their accomplishments. Many of our faculty have received highly prestigious awards in the past decade, including top honors from various professional societies. In addition, several were elected to the esteemed National Academy of Engineering. Our faculty have led their professional organizations, as well as served as editors of top journals and played key roles on the national policymaking stage as leaders in governmental organizations, including the National Science Foundation and the White House Office of Science and Technology Policy.

With clearly identified strategic research directions and a highly collaborative climate, centers and institutes under the Department's purview have also thrived. The U-M Automotive Research Center renewed its contract for $40 million. A first-of-its-kind Mobility Transformation Center and Mcity autonomous vehicle test facility is making headlines around the country, with ME faculty heavily involved in both research initiatives and leadership. In addition, we're shaping the future of emerging manufacturing technologies through faculty leadership of the Alliance for Manufacturing Foresight (MForesight) and the U.S. Department of Defense-funded LIFT Lightweight Innovations consortium. ME faculty have also provided strong leadership in various other large-scale initiatives on campus, including the Robotics Institute, the Exercise & Sports Science Initiative and the Michigan Institute for Computational Discovery & Engineering.

On the educational front, we've increased curricular flexibility for our undergraduates and created the novel RISE (Research, Innovation, Service and Entrepreneurship) program, which emphasizes independent student projects. We have implemented several initiatives to enhance our graduate program, including adding a number of additional and well-received academic and career-focused mentoring events and programs. Our PhD students received highly competitive National Science Foundation Graduate Research Fellowships—among the highest number of recipients from a single department in the country. We launched a new two-year dual degree combining the Master of Science in Engineering in Mechanical Engineering with the Master of Management from the Ross School of Business. Our students also have a number of opportunities globally, with unique programs in China, Germany, Ghana, India and Japan.

Our alumni continue to amaze and we are ever grateful for their incredible support. In 2012, the Department received a significant endowment from loyal and distinguished alumnus Tim Manganello, former executive chairman of BorgWarner Inc. and the BorgWarner Foundation. This generous landmark gift established the first endowed department chair in the history of the College of Engineering.

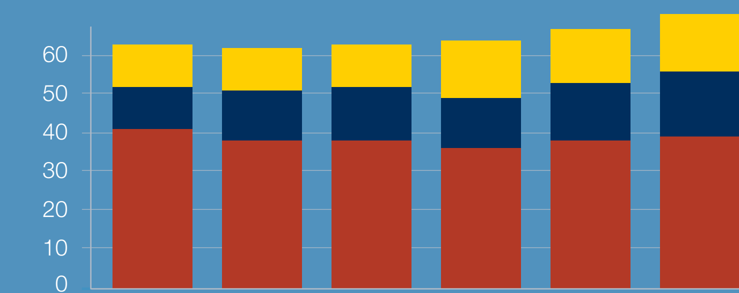
We'll celebrate our rich history, flourishing present and ambitious future during special events on September 21 and 22, and we hope you'll join us. Visit me.engin.umich.edu/me150/schedule for a full schedule of educational (and fun) events.

It has been my great honor to serve as Chair of University of Michigan's Mechanical Engineering department for the last 10 years. To friends far and wide, thank you for your unwavering support over the past decade.

Humbly,
Kon-Well Wang

Tim Manganello/BorgWarner Department Chair and Stephen P. Timoshenko Collegiate Professor
August 2018

Faculty Trends: Tenured and Tenure-Track



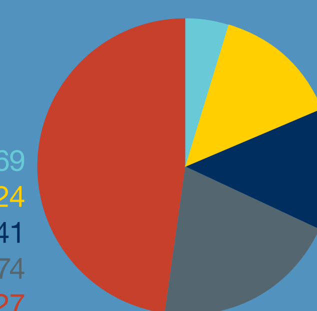
	FA13	FA14	FA15	FA16	FA17	FA18
Assistant	11	11	11	15	14	15
Associate	11	13	14	13	15	17
Professor	42	39	39	37	39	40
Total	64	63	64	65	68	72

Annual Research Expenditures

TOTAL RESEARCH EXPENDITURES
$35,242,935

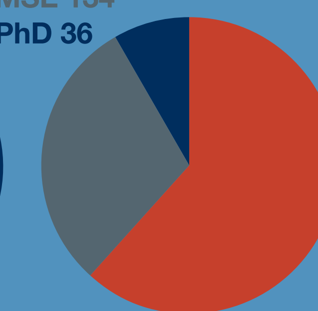
2017–18

NIH	$1,665,169
NSF	$4,969,024
DoE	$4,661,341
DoD	$7,200,774
All Other	$16,746,627



Degrees Conferred 2016–17

BSE 275
MSE 134
PhD 36



Faculty Profile

*Including Emeritus Faculty

10 NAE Members*

79 Society Fellows

5 NSF PECASE or PFF Awards

39 NSF CAREER or PYI Awards

4 Current Journal Chief Editors

73 Current Journal Editorial Board or Assoc. Editor Appts.

Ellen Arruda Named New ME Chair

> Mechanical engineering at Michigan is one of the best places in the world to be if you desire to engage in creative solutions that improve the quality of life and make the world safer, better and cleaner.

Ellen Arruda has been named the new chair of the Department of Mechanical Engineering, effective September 1, 2018.

Arruda, who joined U-M's ME faculty in 1992, will be the 18th chair of the Department, which was founded in 1868.

She succeeds Kon-Well Wang, Stephen P. Timoshenko Collegiate Professor of Mechanical Engineering, who has served as chair since June 2008.

"I am honored and excited to lead this fantastic mechanical engineering department at this time," Arruda said. "The products and processes that mechanical engineers create are critical to our physical future. Mechanical engineering at Michigan is one of the best places in the world to be if you desire to engage in creative solutions that improve the quality of life and make the world safer, better and cleaner."

Recognized as a trailblazer in her field, Arruda's groundbreaking research and teaching have secured her position as 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 had a tremendous impact on improving human health and life, such as advancing technologies for the repair of the anterior cruciate ligament and the development of a shock-absorbing helmet to prevent brain injury.

"Ellen is an eminent scholar who has served the University of Michigan with distinction," Wang said. "I want to thank her for her willingness and passion in taking up such an important responsibility to serve the U-M ME community. This is a truly outstanding department with exceptional people and extraordinary accomplishments, and I firmly believe that it will continue to excel under Ellen's leadership."

Arruda was elected to the National Academy of Engineering in 2017, is president and fellow of the American Academy of Mechanics, a fellow of American Society of Mechanical Engineers (ASME) and fellow and former president of the Society of Engineering Science. She is co-director of the University of Michigan's Exercise & Sports Science Initiative and has joint appointments in the College of Engineering's Macromolecular Science and Engineering Program and Biomedical Engineering Department.

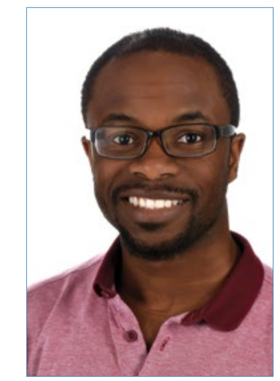
"Ellen's long and accomplished record of research, leadership and service within the Mechanical Engineering Department—and her commitment to its future—make her an ideal leader," said Alec D. Gallimore, who is the Robert J. Vlasic Dean of Engineering, the Richard F. and Eleanor A. Towner Professor, an Arthur F. Thurnau Professor, and a professor both of aerospace engineering and of applied physics."I know that under her guidance, the Department will continue on its path of excellence in both educating the socially conscious mechanical engineers of tomorrow, and producing impactful research in service of the common good."

ME Welcomes New Faculty Members

The ME Department is pleased to welcome Xun (Ryan) Huan, David Kwabi, Serife Tol and Aaron Towne, who are joining the faculty as assistant professors.

XUN (RYAN) HUAN

Huan earned his PhD in computational science and engineering from the Massachusetts Institute of Technology. With a background as a postdoctoral researcher at Sandia National Laboratories in California, his research interests broadly revolve around computational methods for uncertainty quantification, decision-making under uncertainty, data-driven modeling and optimization for engineering applications.



DAVID KWABI

Kwabi obtained his PhD in mechanical engineering from the Massachusetts Institute of Technology and has worked as a postdoctoral fellow at Harvard University. His research interests include electrochemical reactions in non-aqueous metal-O^2 as well as combining electrochemical and in situ spectroscopic techniques to characterize organic redox flow batteries.

SERIFE TOL

Tol received her PhD from the G.W. Woodruff School of Mechanical Engineering at Georgia Tech. She served as a visiting scholar at the University of Illinois at Chicago where she focused on improving sensing in nondestructive testing by wave focusing via graded metamaterials on curved surfaces. Her research interests include smart structures, electromechanical systems, vibrations, elastic wave propagation and metamaterials.

AARON TOWNE

Towne earned his PhD and MS in mechanical engineering from the California Institute of Technology, and worked as a postdoctoral fellow in the Center for Turbulence Research at Stanford University. His research develops low-cost mathematical and computational models that can be used to understand, predict and control the turbulent flow of fluids in various engineering systems. His work draws on ideas from classical fluid mechanics, dynamical systems and controls theory, and data analytics and mining to extract and model the underlying structure within these chaotic systems.

Six ME Students Receive NSF Graduate Research Fellowships

A total of six ME graduate students 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 2018 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:

Shannon Danforth
PhD student
Advisor: **Ram Vasudevan**

Andrew Edoimioya
PhD student
Advisor: **Chinedum Okwudire**

Andrew Gayle
PhD student
Advisor: **Neil Dasgupta**

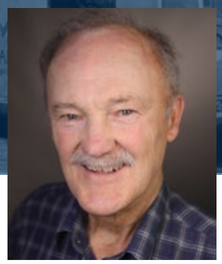
Joshua Nkonge
Master's student
Advisor: **Kathleen Sienko**

Michael Potter
PhD student
Advisors: **Lauro Ojeda, Noel Perkins**

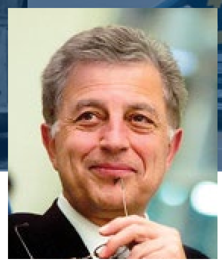
Victor Rodriguez
PhD student
Advisor: **Jesse Capecelatro**

University of Michigan Mechanical Engineering Celebrates 150 Years

As part of the U-M Mechanical Engineering's 150th Anniversary celebration this year, the Department planned a Distinguished Lecture Series featuring world renowned scholars, leaders and distinguished alumni.



JOHN HUTCHINSON
April 6
Abbott and James Lawrence Research Professor of Engineering, Harvard University



PARVIZ MOIN
April 20
Founding Director of Center for Turbulence Research, Stanford University

C.D. MOTE, JR.
May 18
President, National Academy of Engineering
2018 Michael Korybalski Distinguished Lecture

CARLA BAILO
May 24
President and CEO, Center for Automotive Research

CRISTINA AMON
September 10
Dean of Faculty of Applied Science and Engineering, University of Toronto

JON LAUCKNER
September 18
CTO and Vice President R&D, General Motors Company

The University of Michigan Mechanical Engineering Department is in the midst of celebrating a major milestone, its 150th anniversary! ME helped pioneer the field 150 years ago, and continues to be a worldwide leader in research and education, both basic and translational, from transportation engineering to energy, from bio/health to manufacturing and beyond.

Throughout 2018 the Department has celebrated its sesquicentennial with a variety of events, including a distinguished speaker lecture series, culminating on September 21, 2018 with a full day of on-campus activities including panel discussions focusing on the Department's rich history and exciting future. 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.

The special "150 Years in Review" section (page 11) in this report showcases some of the major accomplishments of the U-M ME Department over the last 150 years. Enjoy!

Friday, September 21, 2018 Schedule:

Welcome Reception	9:00 a.m.
Panel Session I: Theme—U-M ME History through Present	10-11:00 a.m.
Chuck Vest Sculpture Dedication	11:30 a.m.
LUNCH Strolling lunch featuring a poster session by ME graduate student presenters	12:00 p.m.
Panel Session II: Theme—U-M ME Present & Future	1:30 p.m.
Open house tours of ME research facilities and learning space, announcement of ME 150th winning student design project and scavenger hunt planned by ME students	3:00 p.m.

Share Your Stories

In honor of U-M ME's 150th Anniversary, the department reached out to its faculty, staff, alumni and current students to find out how the Department has shaped each of their lives with a special "Share Your Story" campaign.

Here is a snapshot of some of the stories we collected. To read more, visit https://me.engin.umich.edu/me150/make-your-mark/share-your-story

TOBY DONAJKOWSKI

Instructional Lab Manager

It is hard to believe that I've been at U-M ME for nine years. Throughout my time here I have met and interacted with so many outstanding individuals who have left an impact on my life. I feel fortunate to have an opportunity to exchange knowledge and play a small part in developing a better engineer. Working directly with the young engineers has been a gratifying and humbling experience. I am appreciative to the U-M Department of Mechanical Engineering for their continued support throughout the years.

ELVHIN ENCARNACION

Current Student

Mechanical Engineering has provided me with a breadth of knowledge to apply into any industry I desire. It just so happens that my dream is to work at an automotive company creating cars. Thanks to ME, I'll be doing just that this summer as I start my engineering career with Fiat Chrysler Automobiles.

SAMUELINA WRIGHT

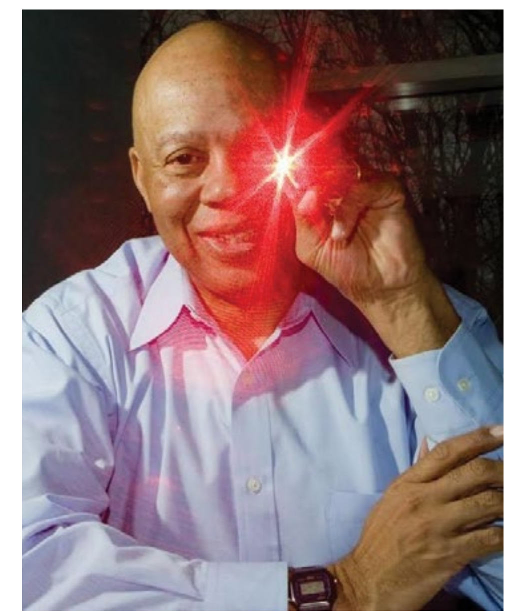
BSE, 2015

Sometimes it's still hard for me to believe, but what I do believe is that the Giant Rubik's Cube project (ME450, 2014) would not have been the same rewarding, challenging or successful learning experience at any other university. The people and resources in the Mechanical Engineering Department fueled the creativity of a project that ultimately shaped my undergrad experience.

DAWN TILBURY

Professor

I interviewed at ME in 1994, while I was still a PhD student. At most places I interviewed, I would have been the first (and only) woman faculty member, whereas when I joined ME in January of 1995, I was one of five women faculty (Maria, Ellen, Diann and Ann Marie), which was great. In the College, we had a group called FEW = Faculty Engineering Women, which met for lunch about once a month to build connections. Those friendships made a large impact on my career as a female engineer.



MARSHALL JONES

BSE, 1965

Within ME, I truly loved design, as well as the mechanics and materials of all lab work. U-M ME's design training led to my fi rst job in high energy physics at Brookhaven National Labs and that same training provided a great foundation for my grad studies at UMass, opening the door to my 44-year career at GE Global Research in laser technology. It was this foundation that led to my election to the National Academy of Engineering and the National Inventors Hall of Fame. I truly love the ME Department at the University of Michigan. Happy 150th Anniversary! Go Blue!

SHERI SHEPPARD

PhD, 1985

When I decided to get my PhD I was fortunate that there was a world-class university in my backyard—the University of Michigan. It was an excellent match. The coursework had just the right balance of theory and application for my interests. The faculty were superb mentors, teachers and role models and the research was intellectually interesting and well supported. Yes, U-M ME was a good fit for me, and that education has served as a solid foundation for my academic career of 32 years as a faculty member in Mechanical Engineering at Stanford University.

MIKE HESS

BSE, 1991

While I was at U-M, I became a Cooperative Education (Co-op) Student at NASA. During my final years at Michigan, I alternated semesters between school and working at the Johnson Space Center in Houston. The space discipline in which I worked was Extravehicular Activities (spacewalking) Operations. I was involved in the planning of missions, training of astronauts in zero-g aircraft or underwater in the water tank and supporting missions in Mission Control. On Space Shuttle Mission STS-37, during the spacewalks, astronauts tested future concepts of translation trollies that could be used for assembly and maintenance of the space station. In preparation for this mission, I remember relying on excellent instruction from U-M ME Professor Barber in mechanics of materials and from Professor Scott in loads and fasteners in order to work out devices and mechanisms the crew would actuate for successful evaluation of the space trollies. The mission was a success and CETA Carts are used on all of the international Space Station spacewalks today for successful maintenance of the station.

SUYI LI

BSE, 2006; PhD, 2014

When I first saw the GG Brown Building it was a massive and confusing collection of fancy classrooms and research labs. Little did I know that it would become my second home over the next 10 years. I became a young professor and I feel proud every time I give my students homework assignments and exam questions from my own class notes at Michigan even though they keep complaining about how difficult they are! (Suyi Li – left in the photo)

CHINEDUM OKWUDIRE

Associate Professor

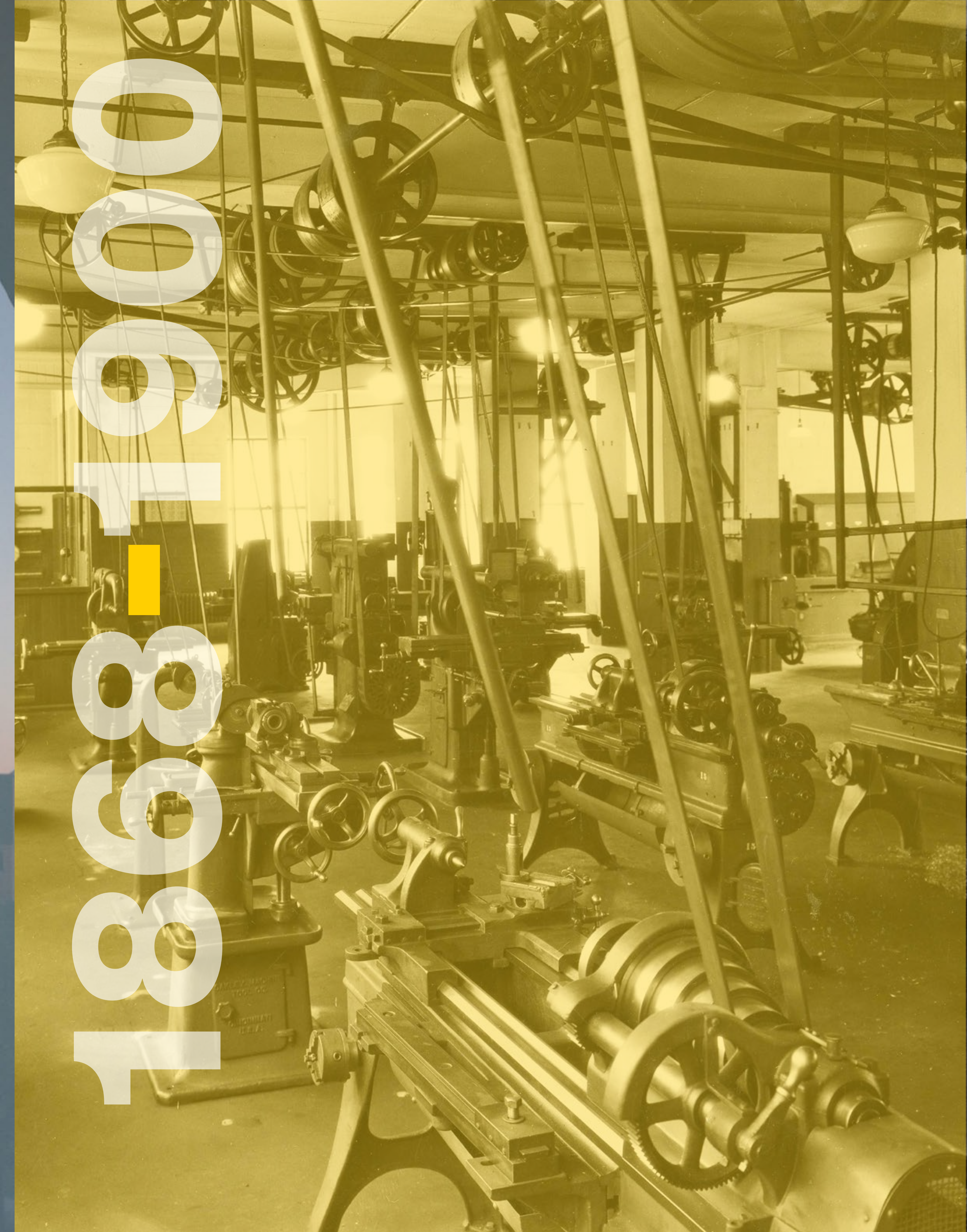
Combine a longstanding reputation of academic excellence with a very warm and supportive climate and you get U-M ME at 150. I'm truly delighted to be a part of this great department at such an auspicious time, and help to shape its next 150 years! (Chinedum Okwudire – right in the photo)

1868–2018

150 YEARS IN REVIEW

CELEBRATING
150
YEARS
1868 M 2018
MECHANICAL ENGINEERING

1868–1900



From its humble beginnings in 1868 as a two-room laboratory with one professor, the University of Michigan (U-M) Department of Mechanical Engineering (ME) has become one of the world's top mechanical engineering programs, with a rich history and a strong, clear vision for the future. We continue to shape the field by conducting innovative impactful research and generating new paradigms as well as achieving education excellence and developing future leaders.

1868-1900: CREATING THE DEPARTMENT

In 1868, the only formal engineering curriculum was in civil engineering, and the American Society of Mechanical Engineers (ASME) would not be established until a dozen years later. U-M professors DeVolson Wood and Stillman Robinson asked the University to offer a separate course to focus on the new fields of machine, power and marine engineering. The regents voted in 1868 to create the program, the first of its kind in the U.S., but the University lacked the resources to maintain it, and it was reabsorbed two years later into civil engineering.

It wasn't until Mortimer E. Cooley, a naval officer, came to Ann Arbor in 1881 that ME at Michigan gained an independent identity. Cooley, an 1878 graduate of the U.S. Naval Academy, was one of a number of naval officers appointed by Congress to university facilities. His assignment was to establish an ME program. Over the next three decades, his leadership laid the foundation for a thriving department.

The initial ME curriculum consisted of Workshop Appliances and Processes; Pattern Making, Moulding and Founding; Mechanical Laboratory Work (Shop Practice in Forging); Machinery and Prime Movers (Water Wheels and Steam Engines); Machine Design; Thermodynamics; Original Design; Estimates, Specifications and Contracts; and Naval Architecture.

At that time, engineering classes were held in the South Wing of University Hall, but there was no laboratory building. To remedy that situation, Cooley used an appropriation of $2,500 from the State of Michigan legislature to construct and equip a two-story laboratory building. A contemporaneous account describes as a " a two-story structure of frame construction with bricks placed edgewise between the studding. The building was heated by an old-fashioned stove on the second floor. In cold weather, ice was melted in a pail of water on top of the stove in order to increase humidity." The new facility contained a foundry, a forge shop, brass furnace, and engine room on the first floor, and a pattern shop and machine shop on the second floor.

THE BLACKSMITHING AND MACHINE TOOL SHOP (SECTION DIVIDER) INCLUDED ITS OWN POWER PLANT AND LINE SHAFTS POWERING THE BELT-DRIVEN MACHINES.

THE FIRST MECHANICAL LABORATORY (ABOVE) WAS BUILT FOR $2,500 IN 1882, IT HOUSED A FOUNDRY, FORGE ROOM, BRASS FURNACE, ENGINE ROOM, MACHINE ROOM AND PATTERN SHOP.

DEPARTMENT CHAIRS

1881 to 1904: Mortimer E. Cooley
1904 to 1917: John R. Allen
1917 to 1937: Henry C. Anderson
1937 to 1940: John E. Emswiler
1939: Ransom S. Hawley (Interim)
1940 to 1951: Ransom S. Hawley
1951 to 1955: Edward T. Vincent
1955 to 1956: Wyeth Allen
1956 to 1965: Gordon Van Wylen
1965 to 1966: Arthur Hansen
1966 to 1974: John A. Clark
1974 to 1975: J. Raymond Pearson (Interim)
1975 to 1978: J. Raymond Pearson
1978 to 1981: David Pratt
1981 to 1982: Richard E. Sonntag (Interim)
1983 to 1992: Richard E. Sonntag
1992 to 1998: Panos Y. Papalambros
1995: James R. Barber (Interim)
1998 to 2001: A. Galip Ulsoy
2001 to 2007: Dennis N. Assanis
2007 to 2008: Panos Y. Papalambros (Interim)
2008 to 2018: Kon-Well Wang
2018 to present: Ellen Arruda

MORTIMER E. COOLEY, U-M ME DEPARTMENT CHAIR FROM 1881-1904.

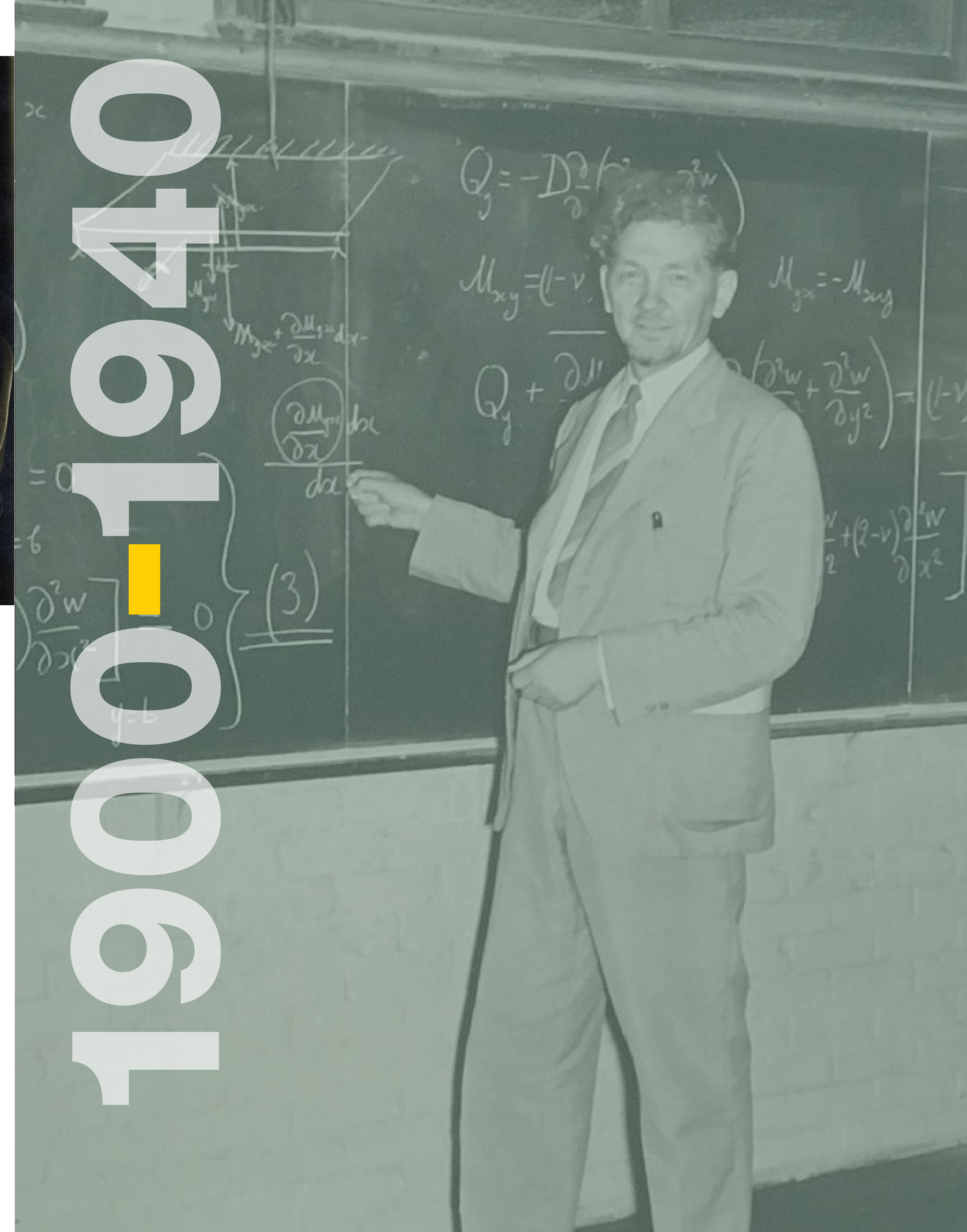
"How well I remember my first class in this little shop. Six engineers were taking the course. The first lesson was at the forge. I taught them how to build a fire. Then I wanted a piece of iron to heat. At the back door there was a wagonload of scrap of different kinds of metal, and I sent the members of the class to bring me back a piece of wrought iron. Much to my surprise not one of the six could identify wrought iron, cast iron, steel, or anything else in the pile. I asked the differences between the various kinds of metal, and every last one of them knew the chemical differences and the process of manufacture, but not one of them could identify one piece of metal from another. That incident thoroughly convinced me of the need from practical work to acquaint engineers with the characteristics of the materials they would be using after graduation."

—from *The Scientific Blacksmith* (1947) by Mortimer E. Cooley

Cooley and other faculty also arranged for students to make visits to neighboring businesses. An entry in the University catalogue of 1890 explains: "As often as may be practical, visits will be paid to the neighboring manufacturing establishments for the purpose of acquiring a knowledge of the methods employed in building and in the construction of bridges, machinery and ships. In the spring of 1886, members of the classes in civil and mechanical engineering spent a week, under the guidance of Professor M.E. Cooley, in visiting industrial works at Detroit, Cleveland and Pittsburgh."

During the 23 years of the Cooley era, the Department acquired a strong curriculum, launched its first successful building program, and formed a strong relationship with business and industry. In 1904, Cooley was named dean of the College of Engineering, a post he held for the next 24 years.

1900-1940



With a strong foundation built during the Cooley era, the ME Department—as well as the entire engineering program at U-M—was primed to step into a leading role in engineering education in the 20th century. Drawing students from across the country and throughout the world, the engineering student body grew tenfold over the next 40 years; graduate degrees were offered for the first time; labs were updated and equipped with modern instrumentation; and independent research projects became important academic endeavors. The University strengthened its relationships with industry and other schools, and interdisciplinary joint-degree programs with law and business were created. The Department grew from a fledgling organization to one of the nation's leaders in mechanical engineering education.

1900-1940: BUILDING NATIONAL PROMINENCE

CURRICULUM

In the 1800s, ME had emphasized steam power and manufacturing machinery almost exclusively. But the world of science and industry was changing, and the Department changed with it.

In 1910 Felix Pawlowski, a young scientist from Poland, arrived in the U.S., determined to become America's first aeronautical engineer. But when he sent letters to engineering colleges around the country asking to be given the chance to start an aeronautics program, he received mostly negative replies: the field was too new and there was no assurance that it would amount to anything. But Mortimer Cooley was visionary. He appointed Pawlowski to the ME faculty and encouraged him to create an aeronautical engineering course of study. The first of its kind in the U.S., the new course debuted in 1914, just 11 years after the Wright brothers' historic first flight at Kitty Hawk, with the first degree awarded in 1917.

FACILITIES

As the Department grew, the need for advanced facilities grew with it. In 1904, West Engineering—the building that would become the symbol of Michigan engineering—was constructed. Now known as West Hall, the building's laboratories were among the most sophisticated in the country at the time.

The equipment in the General Mechanical Engineering Laboratory included steam power machinery; internal combustion engines; and air compressors, among other items. The Hydraulic Lab, which occupied a 40-by-60-foot space on two floors, featured a canal that conveyed water from the naval tank to a well that furnished the suction supply for the pumps. The Physical Testing Laboratory tested materials for strength. And the Highway Laboratory tested materials used in road construction.

STEPHEN P. TIMOSHENKO (SECTION DIVIDER) BECAME KNOWN AS THE WORLD'S LEADING AUTHORITY IN APPLIED MECHANICS.

AUTOMOTIVE ENGINEERING

ME's program in automotive studies began at about the same time as the auto industry did, offering its first course, Gasoline Automobiles, in 1913.

By 1914, ME had gained a strong reputation in automotive engineering, and as World War I began the Department was called upon by the government to help in the war effort. Over the next few years, ME faculty trained 1,081 Army personnel in automotive engine repair.

In 1916, Walter Lay joined the ME faculty with a mandate to create a lab and a slate of automotive courses. The Walter E. Lay Automotive Laboratory is a good example of how the Department responded to new directions in industry. Lay partnered with automotive manufacturers to carry out pioneering research. The lab was one of the first to present comprehensive experimental data showing the advantages of streamlining, and undertook other studies to determine optimal highway grades, explore engine heat balance, test and improve automotive parts, and improve car safety, car noise and riding comfort.

INDUSTRIAL AND PRODUCTION ENGINEERING

The auto industry established southeastern Michigan as the home of U.S. manufacturing, with world-changing innovations such as the assembly line and interchangeable parts. In response to a dramatic evolution in industrial practices and processes, the Department created a program on the leading edge of the discipline. Scientific Shop Management, introduced in 1915, featured the study of applications of scientific management in manufacturing plants. During World War I, it was expanded to include two courses in training of officers of the Ordnance Department of the Army – the first such course offered by an American university.

ORLAN W. BOSTON AND MANUFACTURING SCIENCE

In 1921, Orlan W. Boston joined the faculty. Cooley assigned him the task of developing courses that would combine the disciplines of design, metallurgy and production. The Department soon was playing a major role in establishing the scientific basis for manufacturing processes. In 1934, Boston was named chair of the Department of Metal Processing in 1934, and in 1936 was named Custodian of the Gaging and Measuring Laboratory of the Detroit Ordnance District. By 1936, enrollment in metal processing courses was so large that crowded sections were taught every half-day during the week.

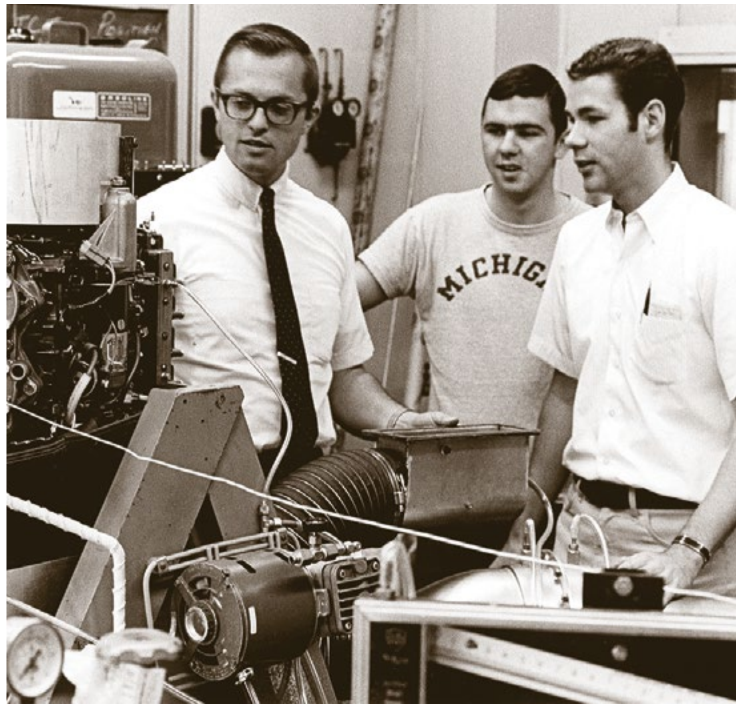
STEPHEN P. TIMOSHENKO AND APPLIED MECHANICS

Stephen P. Timoshenko was a member of the faculty from 1927 to 1936, who became known as the world's leading authority in applied mechanics. His work gave birth to the science-based engineering education that is now the standard all over the world. Timoshenko delineated the essential rules for how structures deform under stress, established the foundations of the theory of the elastic behavior of solid matter and introduced scientific and mathematical approaches to mechanics instruction. Under his leadership, Michigan became the first university in the nation to offer bachelor's and doctoral programs in engineering mechanics.

Timoshenko also introduced scientific and mathematical approaches to the teaching of mechanics. During his tenure, U-M established the first bachelor's degree program in engineering mechanics in the nation as well as the first doctoral degree. During the course of his career, Timoshenko wrote 18 textbooks that were translated into 36 languages. He was the recipient of numerous honorary degrees, and in 1948 the ASME named a medal after him to honor his contributions.

By 1940, the Department was well established as one of the leading mechanical engineering programs in the country. The production engineering group carried out world-recognized research for the War Production Board during World War II.

The years immediately before and after World War II brought significant changes to the Department. The "space race" began, industry was developing new technologies, and the Cold War demanded advanced military systems. Government and business alike turned to universities to help meet these challenges. For the first time, funded research projects sponsored by NASA, the Department of Defense, and private industry became an important focus for the Department.



1940-1970: THE POSTWAR ERA

In 1959, the University of Michigan-Dearborn was established. ME faculty including Raymond Pearson, Axel Marin, Howard Colby and Gordon Van Wylen were instrumental in the creation of the ME program on the new regional campus.

ME faculty were also responsible for establishing the Bioengineering program, with ME professor Glen Edmonson its founding father. The program continues today as Biomedical Engineering.

RESEARCH

The new emphasis on research was seen in both traditional areas and newly emerging technologies. One of the first ME faculty to be heavily involved was Edward Vincent, who won international distinction with Gas Turbines, the first book of its kind. The production engineering group, which included Orlan W. Boston, Robert Caddell, Lester Colwell, Joseph Datsko, William Gilbert, and Kenneth Ludema, carried out world-recognized research on surface roughness measurement and machinability of exotic materials as requested by the War Production Board during World War II.

Other important research included the Orthetics Research Project in the School of Medicine (sponsored by the Department of Vocational Rehabilitation and the National Science Foundation) to develop assistive devices for the upper limbs of disabled persons. ME researchers on this project included Raymond Pearson, Robert Juvinall, Rune Evaldson, and Robert Hess.

Throughout the 1960s, faculty members Wen-Jei Yang, Herman Merte, Vedat Arpaci, and John A. Clark worked on projects that had an impact on the design of NASA's Saturn launch vehicle.

THE LONG-DURATION EXPOSURE FACILITY (LDEF) (SECTION DIVIDER) HELD SAMPLES FROM PROFESSOR FELBECK.

ME FACULTY DAVE COLE (ABOVE) WORKS WITH STUDENTS IN THE AUTO LAB TEST CELL. COLE IS THE FORMER DIRECTOR OF THE U-M COLLEGE OF ENGINEERING'S OFFICE FOR THE STUDY OF AUTOMOTIVE TRANSPORTATION.

Government-funded research related to nuclear power was carried on in the 1960s. Frederick G. Hammitt's work on cavitation in liquid metal in breeder reactors and Edward Lady's doctoral research on boiling at low head flux were two important examples. And, in another emerging technology, Lester Colwell did pioneering work on numerical control of machines.

In the 1960s, the total contract research conducted in ME labs was estimated at $1.1 million. Faculty publications numbered about 80, including three textbooks.

CURRICULUM

The graduate program expanded in tandem with the Department's research activities. Only 21 PhDs were conferred during the first 70 years of the Department's existence. For the period 1940 to 1970, that number soared to 151.

In 1958, ME got a first taste of the technology that would one day revolutionize engineering education and research, when faculty members attended the Ford Foundation-sponsored Project on the Use of Computers in Engineering Education. They learned about the University's mainframe computer and how it could be used in teaching and research. Faculty began to assign keypunch computer problems in classes.

In 1961, the undergraduate program was completely revamped. Then-chair Gordon Van Wylen described the reorganized curriculum in the 1961 annual report: "A complete reorganization of the undergraduate laboratories has been effected....It is anticipated that this will make the lab work a more significant educational experience for the student and that the theoretical and experimental aspects of engineering will be more effectively related to each other."

FACILITIES

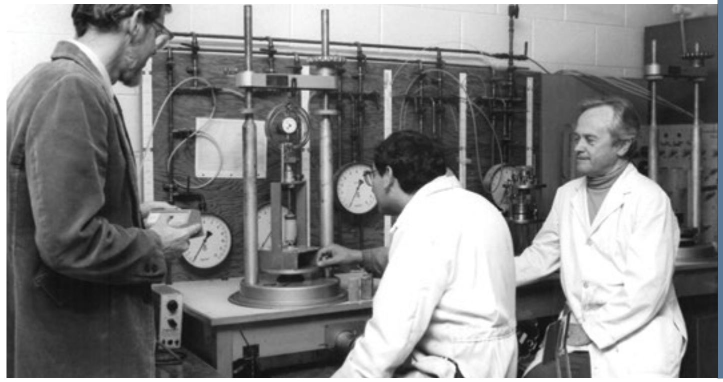
By the early 1950s, it was apparent that the College's old buildings were no longer adequate. In 1956, the Walter E. Lay automotive laboratory was completed, with the state of Michigan providing the $1.85 million construction costs; Michigan industries added an extra $500,000 for equipment, Steelcase donated the furniture and International Nickel Company donated a mobile lab. In 1958-1959, researchers in thermodynamics, heat transfer and fluid mechanics moved to new facilities in the GG Brown Building on North Campus.

In 1953, the Michigan Digital Automatic Computer (MIDAC) was designed and built at the Willow Run Research Center. One of only 20 high-speed electronic digital computers in the country, it was said to be "some 20,000 times faster than a professional mathematician using a desk calculator," (TechniUM + No. 18, June 1980). In 1959, the Board of Regents authorized construction of a new Computing Center on North Campus, with powerful mainframe computers and a terminal system known as the Michigan Terminal System (MTS).

When the Department was established in the late 1800s, engineers prepared for careers in railroads, surveying, shipbuilding or manufacturing. The role of the mechanical engineer has evolved since then, expanding to new industries like automotive engineering, hydraulics, cryogenics, space technology and nuclear power. By the end of the 20th century, the field added the study of lasers, solar energy, automation and control, acoustic emission, composite materials and flexible manufacturing.

MOUNTED ON A CHEVROLET CHASSIS, THE "BLUE BIRD" (ABOVE) SERVED AS ONE OF THE UNIVERSITY'S FIRST TEST VEHICLES. ITS EXOTIC DESIGN HELPED TO DETERMINE AIR RESISTANCE TO MOTION IN LAND VEHICLES, AND TO EXPLORE THE EFFECT OF CHANGES IN VEHICLE SHAPE. IN THE DAYS BEFORE STRAIN GAUGES, LAY SUSPENDED THE SHELL OF THE "BLUE BIRD" ON AN ASSEMBLY OF SCALES TO MEASURE WIND RESISTANCE WHILE DRIVING.

Computers made it possible to explore many problems in traditional research areas that were previously inaccessible. Sponsored research and graduate programs grew rapidly.



OTHER RESEARCH OF THIS PERIOD:

- Samuel Clark (adhesion and reliability of flexible composites)
- Maria Comninou (crack closure and contact at interfaces)
- Deba Dutta (computer-aided design and manufacturing)
- David Felbeck (failure and toughness of engineering materials);
- Julian Frederick (ultrasonic imaging and acoustic emissions);
- Kenneth Ludema (rheology and tribology);
- Christophe Pierre (vibration and wave localization in spatially repetitive structures with imperfections);
- Albert Schultz (biomechanics of mobility impairments in the elderly);
- Richard Scott (optimization of layered composite media vibration and wave propagation in rotating elastic structures);
- Leonard Segel (vehicle dynamics);
- George Springer (structure of rarefied rocket plasma);
- Gretar Tryggvason (bubbles and droplets);
- Wen-Jei Yang (thermal fluid phenomena in biological, anatomical and physical systems);
- Vedat Arpaci (efficient drying versus pulse combusters);
- Michael Chen (thermocapillary flows in welding and crystal growth);
- Herman Merte (forced convection boiling in microgravity);

1970-2000: LEADERSHIP IN HIGH TECHNOLOGY

The first female faculty member, Maria Comninou, joined Applied Mechanics in 1974; the first African American faculty member, Elijah Kannatey-Asibu, Jr., joined ME in 1983; the long-awaited move to North Campus was realized; and the Department gained strength through its merger in 1979 with the Applied Mechanics Department, acquiring the new name Mechanical Engineering and Applied Mechanics (MEAM).

By 2000, the Department was ranked consistently among the top five ME departments by U.S. News & World Report and the National Research Council, and occasionally among the top two or three. Thirteen percent of ME Faculty were now female—the largest percentage of any ME department in the country at the time.

RESEARCH

Total research expenditures climbed from about $500,000 per year in the early 1970s to over $20 million in 2000, enabling steady growth in the doctoral program. This emphasis not only increased engineering knowledge, it also enriched the educational experience of all MEAM students.

The energy crisis of the mid-1970s sparked a search for alternative energy sources, and solar energy was considered one of the most promising. John A. Clark established the Department's Solar Energy Laboratory in 1973, which served as the chief source of technical advice and research for all the solar energy companies in Michigan. Clark later became technical director of Star Pak Energy Systems Company, which developed and marketed the devices conceptualized in the U-M solar lab.

ME PROFESSOR NOBORU KIKUCHI AND STUDENT (SECTION DIVIDER), FROM THE EARLY 70'S USING A COMPUTER FOR ENGINEERING ANALYSIS. KIKUCHI IS A WORLD RENOWNED SCHOLAR IN ADAPTIVE FINITE ELEMENT METHODS INCLUDING AUTOMATIC MESH GENERATION AND REMISING SCHEMES FOR NONLINEAR PROBLEMS IN MECHANICAL ENGINEERING AND APPLIED MECHANICS.

ME made strides in traditional areas as well. In the 1970s, important automotive research was carried out by Donald Patterson, William Mirsky, Jay Bolt and David Cole, including a project to see if thermal reactors could control emissions as well as catalytic converters. The group's research revealed the limitations of thermal reactors, paving the way for universal use of catalytic converters. In 1978, the Office for the Study of Automotive Transportation (OSAT) was founded; OSAT continues today as the nonprofit Center for Automotive Research.

Automotive faculty carried their technology beyond the University and established private companies. Cole, Mirsky and Patterson were among the founders of MI Automotive Research. Later, the group founded QED Environmental Systems to manufacture a pump design they invented for obtaining water samples around dump sites. Departmental depth and technical expertise also led to the establishment of the Automotive Research Center (ARC) in 1994, under the leadership of Panos Papalambros and colleagues, in partnership with the U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC). The emphasis on automotive engineering also led to the creation of other centers including a new $5 million General Motors Satellite Research Laboratory in 1998.

The emerging field of robotics research saw many major and lasting contributions from the research conducted by Yoram Koren and Johann Borenstein. They developed a potential field method for mobile robot navigation, an electromechanical snake robot, an electronic guide cane for the blind and many other robotic technologies. Their mobile robot CARMEL took first place in the 1992 artificial intelligence robotics competition.

Research in manufacturing engineering also flourished. Elijah Kannatey-Asibu used acoustic emission sensing for tool wear and breakage monitoring. Jyoti Mazumder explored laser processing of materials. A Center for Dimensional Measurement was established by Sam Wu with funding from industry and the NSF. Wu, together with his students, Jun Ni and Jack Hu, also established the "2-mm Program" with funding from the National Institute of Standards and Technology and the automotive industry, which had a major impact on the U.S. auto industry. After Wu's untimely death in 1992, the Department hired Ni and Hu; they co-directed the S. M. Wu Manufacturing Research Center, which was named in his honor.

Koren and Galip Ulsoy developed the concept of Reconfigurable Manufacturing Systems, which was crucial to the establishment, in 1996, of the NSF-funded Engineering Research Center (ERC) for Reconfigurable Manufacturing Systems (RMS). With NSF grants, Michigan manufacturers and the state of Michigan, the ERC/RMS would develop RMS-enabled factories capable of readily designing new production systems, sensors, controls and machining equipment. Michigan engineers helped factories respond quickly to market demands, reduce product-development time and expense, offer more choices to consumers and become a driver of economic growth.

FACILITIES

In 1983, the Department completed the move to North Campus that had begun some 30 years earlier.

During the 1970s, computing was performed using time-sharing on MTS. The personal computer revolution came to the College in 1983, with the establishment of the Computer-Aided Engineering Network (CAEN). CAEN operated one of the largest integrated, multi-vendor workstation networks in the academic world. More than 2,000 workstations and microcomputers were distributed in offices and labs; the system was recognized as a model of distributed computing environment for engineering and computer science instruction and research.

The early 1980s also saw ME faculty employ the first laboratory data acquisition and control systems in their research, and the establishment of a laboratory course equipped with PCs for real-time data acquisition, signal processing and control.

CURRICULUM

In the 1980s, ME established itself as a leading department as reflected in its rankings by *U.S. News & World Report* and the National Research Council.

SOLAR CAR MILESTONES

Since 1990 the U-M Solar Car team has won 6 consecutive National Championships, 9 overall, 6 Top-3 World Finishes and 1 International Championship

1988: GM issues a challenge to college students across the country: design and build a solar car to race from Florida to Michigan in Sunrayce '90.

JUNE 1990: A team of U-M students arrived at the starting line with its "Sunrunner" vehicle, which takes 1st place, crosses the finish line with a 90-minute lead over the second-place finisher.

NOVEMBER 1990: Sunrunner competes in the World Solar Challenge in Australia and finished third in the world.

1991: Sunrunner was retired from competition and put on exhibit at the Henry Ford Museum in Dearborn, Michigan.

1993: Sunrayce '93, a new team of Michigan students begins to build Michigan's second solar car, "Maize & Blue," for a 1,000-mile race from Texas to Minneapolis. U-M pulled into the lead on the fifth day and finished in 1st place, again 90 minutes ahead of the second-place car.

2001: M-Pulse wins American Solar Challenge and finishes 3rd in the World Solar Challenge

2005, 2008, 2009, 2012 AND 2014: Momentum, Continuum, Infinium, Quantum, and Quantum II all earn first place finishes in the American Solar Challenge, respectively.

2017: Novum takes home U-M's most successful Bridgestone World Solar Challenge finish yet in a historic second-place win. Novum is the smallest, most aerodynamic Michigan solar car ever.

In the spring of 1992, new chair, Panos Papalambros appointed an undergraduate curriculum review committee to examine the curriculum at other engineering schools and conduct alumni surveys. A year later, the committee presented a preliminary proposal for curriculum revisions. It maintained the strong core in engineering science but put more emphasis on hands-on experience, creative problem-solving and communications and teamwork. Two major changes were implemented: a reorganization of the required laboratories, and the establishment of a sophomore class in design and manufacturing to include computer-aided design and hands-on experience in a machine shop.

The senior project-based design course, ME450, utilized engineering projects form local industry, and became a role model for senior design project courses throughout the College of Engineering.

In addition to benefiting from an enhanced formal curriculum, undergraduate students engaged in many extracurricular activities, with 95+% of all ME undergrads involved in co-ops and summer internships in companies around the world.

The Department also developed the Master of Engineering and Doctor of Engineering professional degree programs, and their delivery by distance learning systems to engineers in industry. The first M. Eng. and D. Eng. Degrees were awarded in manufacturing in 1994. Galip Ulsoy, dounding director of the manufacturing program, developed an agreement with General Motors for its engineers worldwide to enroll in the M. Eng. program via distance learning technologies.

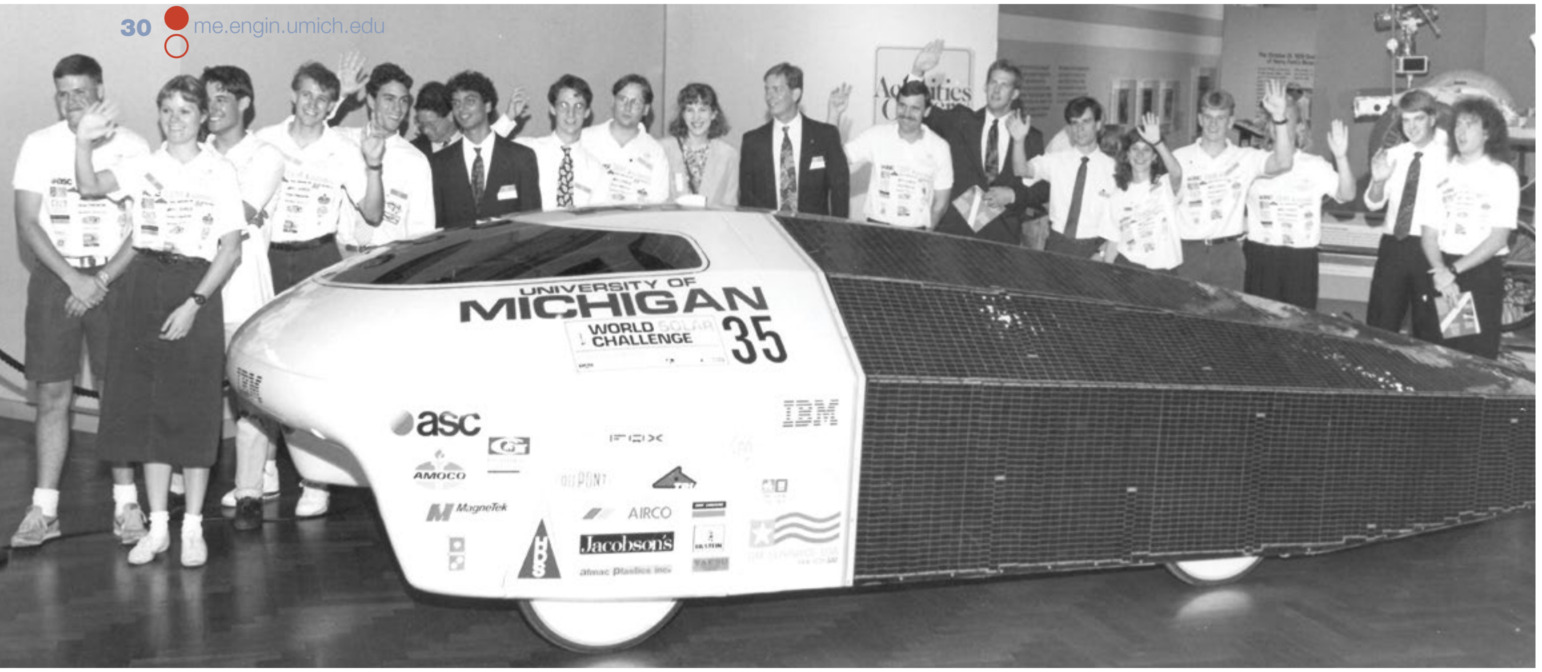
CHIA-SHUN "GUS" YIH AND FLUID MECHANICS

Chia-Shun Yih was the Stephen P. Timoshenko Distinguished University Professor in the Department from 1968 until his retirement in 1988. He was one of the most honored professors in the Department's history and was a member of the U.S. National Academy of Engineering (NAE) and the Academica Sinica in China. His contributions to the literature of fluid mechanics were extensive and important, and his books are classic references for students and researchers in the field.

MILTON CHACE AND MECHANICAL DYNAMICS SOFTWARE SOLUTIONS

As a doctoral student in the 1960s and faculty member in the 1970-80s, Milton Chace conducted pioneering research in computer-aided engineering and mechanical dynamic system analysis, which enabled computerized mechanical simulations that would eliminate the need for expensive prototypes. In 1969, Chace's research team developed a two-dimensional program named DRAM (Dynamic Response of Articulated Machinery), a program that included a computer language that provided automated development of the correct differential equation set for whatever problem was modeled by the user. Later, PhD student Nicholae Orlandea created a prototype three-dimensional computer simulation program, which he named ADAMS (Automated Dynamic Analysis of Mechanical Systems). In 1977—in an early and highly successful example of the increasing sophistication of the Department's involvement in technology transfer—Chace and Michigan Engineering colleagues Mike Korybalski and John Angell formed Mechanical Dynamics, Inc. (MDI).

CHIA-SHUN "GUS" YIH (ABOVE) WAS THE STEPHEN P. TIMOSHENKO DISTINGUISHED UNIVERSITY PROFESSOR IN THE MECHANICAL ENGINEERING AND APPLIED MECHANICS DEPARTMENT FROM 1968 UNTIL HIS RETIREMENT IN 1988. HE IS ONE OF THE MOST HONORED PROFESSORS IN THE DEPARTMENT'S HISTORY.



CHARLES M. VEST: HOLOGRAPHY, TOMOGRAPHY AND ACADEMIC LEADERSHIP

A graduate student in ME, Charles M. Vest stayed on at Michigan and became a faculty member in the Department. Vest's early work on holographic measurement of temperature fields in natural convection (inspired by U-M professor Emmett Leith and his colleagues in Electrical Engineering) led to experiments in computed tomography. In the early 1970s, Vest and his students considered the experimental information generated by multiple beams traversing fluids in various directions and realized that three-dimensional measurements of the density of fluids could be obtained from interferometric measurements. The procedure for obtaining these measurements is similar to that for getting medical images from CT and MRI scanners, and Vest's work led to a powerful imaging method widely used to validate predictions in combustion, aerodynamics and heat transfer. Vest went on to serve as associate dean and dean of COE, then provost of the University. From 2000 to 2014 he was president of the Massachusetts Institute of Technology (MIT). He also served as president of the National Academy of Engineering.

SHIEN-MING "SAM" WU: STATISTICAL METHODS AND MANUFACTURING ENGINEERING

In 1987, Shien-Ming "Sam" Wu joined the Department after 30 years on the faculty of the University of Wisconsin. Wu was the first researcher to introduce advanced statistical techniques to manufacturing research and development, and brought rigor and quantitative methods into manufacturing processes and systems. He created a "game changer" for the manufacturing industry by building the strongest academic/industry collaborative research program in the nation. With funding from the NIST Advanced Technology Program, he created the "2-mm Program." Wu's impact was profound, and his contributions have modernized manufacturing processes of major industries in the U.S. and abroad. His legacy continues with research conducted in the S. M. Wu Manufacturing Research Center, led by his former doctoral student Jun Ni.

ALBERT B. SCHULTZ: SPINAL BIOMECHANICS AND FALLS IN THE ELDERLY

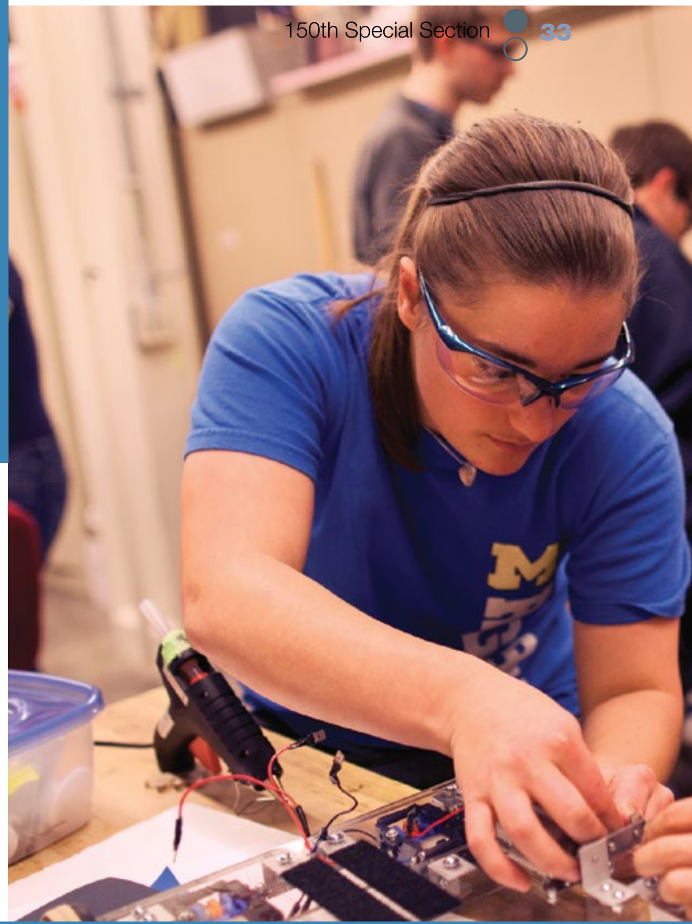
Albert B. Schultz started his career at the University of Illinois in Chicago, moving U-M in the mid-1980s. He was recognized as a leader in whole body biomechanics for his research on spinal mechanics, spinal cord injuries and balance and falls in the elderly. His research explored the assessment, treatment and prevention of physical problems and injuries that commonly arise in older populations. Schultz was among the most honored faculty to serve in the Department. He retired in 1999, but the biomechanics lab he established continues under the leadership of his long-time colleague and collaborator James Ashton-Miller.

In 1999-2000 MEAM once again became the "Department of Mechanical Engineering." This was a clear victory for U-M's science-based engineering education championed by Timoshenko. In fact, the applied mechanics program had so transformed Mechanical Engineering that the distinction between the two was no longer valid.

U-M FIRST SOLAR CAR, SUNRUNNER (ABOVE), RACED IN THE 1990 SUNRAYCE, WON THE EVENT AND WENT ON TO PLACE THIRD IN THE 1990 WORLD SOLAR CHALLENGE. SUNRUNNER IS ON DISPLAY AT THE HENRY FORD IN DEARBORN, MICHIGAN.

ERC: BRINGING RMS SCIENCE TO THE FACTORY FLOOR

Founded by Yoram Koren in 1996, the Engineering Research Center for Reconfigurable Manufacturing Systems (ERC/RMS) helps develop new scientific methodologies and innovative equipment that enable companies to launch production faster, with higher productivity and improved parts quality. RMS technologies give manufacturers the production capabilities they need when they need it—an important advantage in the global marketplace.



Once again, ME was faced with the challenge of redefining itself. Mechanical engineers were needed to address new problems like micro-electro-mechanical systems (MEMS), nanomanufacturing, robotic rehabilitation and biomechanics at the cellular and molecular level.

2000-2018: 21ST CENTURY REDEFINED

As a means to address the rapid changes occurring in the early 2000s, ME chair Galip Ulsoy joined forces with mechanical engineering department heads in the Big Ten Plus Group, which had submitted a proposal to NSF to hold a workshop in January 2002 entitled "Redefining Mechanical Engineering." The workshop addressed the discipline's evolving nature and attempted to redefine the field by focusing on how current trends were likely to affect the future of mechanical engineering research and education. Ulsoy and the next ME chairs Dennis Assanis and Kon-Well Wang used this as a blueprint to grow the Department into emerging areas.

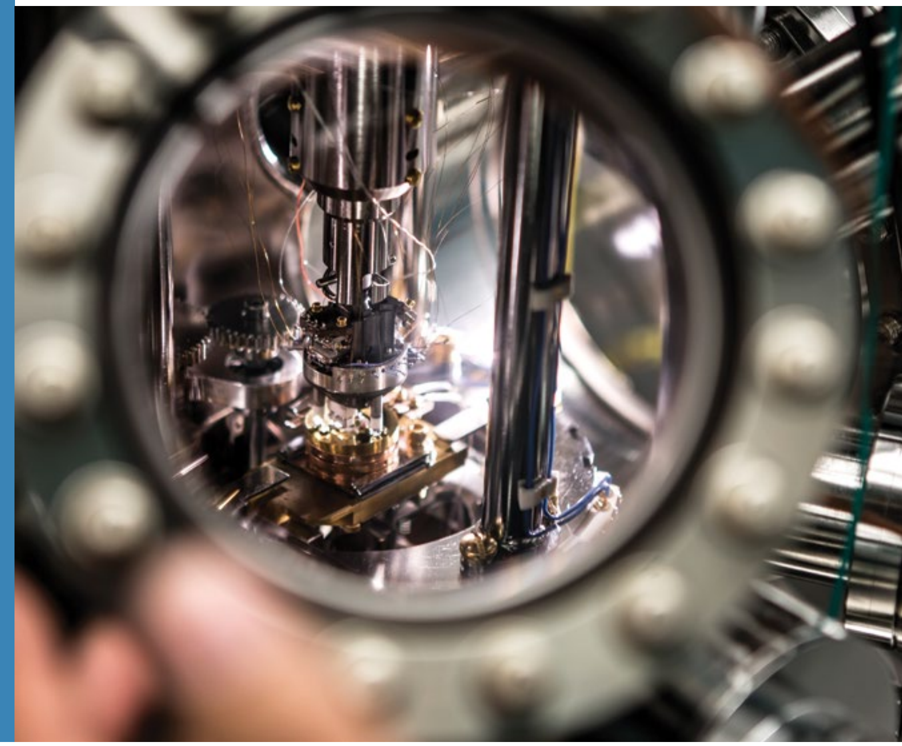
Later events, under the leadership of ME chair Kon-Well Wang, continued the national discussion. As a member and chair of the ASME Department Heads Executive Committee, Wang developed agenda items at ASME's Department Heads Forum and its International Mechanical Engineering Education Leadership Summit, which kicked off several new initiatives among ME chairs nationwide. Wang also encouraged U-M ME colleagues to serve as panelists and speakers: Sridhar Kota spoke about how to drive a national agenda at the White House Office of Science and Technology Policy; Diann Brei described U-M's ME curriculum flexibility enhancement and RISE program; Noel Perkins addressed U-M's major facility renovation for design/manufacturing education; and Steve Skerlos spoke about sustainable manufacturing). These engagements provided the Department with a platform to more significantly impact the academic community.

In 2010, under chair Kon-Well Wang, a strategic plan was developed. Annual faculty retreats were held to follow up on strategic action items. Goals included undergraduate and graduate education, faculty and staff development, facilities and space and a research and hiring focus on: (1) bio- and health systems, (2) emerging manufacturing, (3) energy and environment and (4) future transportation.

PROFESSOR YORAM KOREN (SECTION DIVIDER), DIRECTOR OF THE ENGINEERING RESEARCH CENTER FOR RECONFIGURABLE MANUFACTURING SYSTEMS AT U-M, INSPECTS THE INDEXING MECHANISM OF THE NEW 'ARCH-TYPE' RECONFIGURABLE MACHINE TOOL IN THE ERC/RMS TESTBED.

MILESTONES

- In 2008, College of Engineering departments began handling their own development activities.
- ME Chair Kon-Well Wang has worked closely with the College Advancement Office to raise funds for ME's strategic needs.
- $15 million in private funds and $30 million from the state of Michigan were raised to fund the GG Brown addition and other major renovation projects.
- Tim Manganello, chief executive officer of Borg Warner, Inc., and the BorgWarner Foundation endowed ME's chair with a $2 million gift. The first endowed department chair in the College, the gift enabled new departmental initiatives to achieve planned strategic goals.
- ME has now created a comprehensive 9,000 person database to help enhance communication with alumni.



RESEARCH

Extensive cutting-edge research led to commercialization efforts by ME faculty:

- Jyoti Mazumder established POM Group Inc. (now DM3D Technology LLC) to develop laser direct metal deposition machines
- Noel Perkins developed an ultra-small MEMS-based inertial measurement unit, which served as the basis of commercialization efforts in fly fishing (Castanalysis LLC).
- Steve Skerlos' research in cutting fluids led to two startups: Accuri Cytometers and Fusion Coolant Systems.
- Shorya Awtar's innovations in laparoscopic and minimally invasive instruments helped established FlexDex Surgical.
- Sridhar Kota's research in compliant mechanisms via his company, FlexSys, Inc. in collaboration with the U.S. Air Force and NASA created a revolutionary shape-changing aircraft wing.
- Karl Grosh's research led to the creation of Vesper Technology, which uses piezoelectric materials to create the most advanced Micro Electro-Mechanical (MEMS) microphones on the market.
- Shorya Awtar comes out with U-M ME's startup FlexDex Surgical's first product, a simple, ergonomic and intuitive "needle driver" for stitching inside the body. It has since been used all over the world in operations.

During this period, the number of tenure track faculty grew from about 50 to 72. New faculty brought expertise in emerging areas, such as the science, design and manufacturing of micro- and nanoscale devices; biomechanics at the cellular and molecular levels; connected and automated vehicles; rehabilitation robotics; and energy storage materials. Under the leadership of successive associate chairs for graduate education—Karl Grosh, Steve Skerlos and Kevin Pipe—the ME PhD qualifying exams were redesigned and further enhanced.

Throughout its history, the Department has taken full advantage of its southeastern Michigan location and has excelled in automotive and manufacturing engineering. Close ties to engineers working in related industries were developed, and many students have conducted research and undertaken projects in special facilities in nearby industries.

The TARDEC-funded Automotive Research Center (ARC) expanded its operation under the leadership of Dennis Assanis and Anna Stefanopoulou. Automotive saw an increasing emphasis on control systems to reduce emissions, improve fuel economy and enhance safety, and engineers focused on new technologies such as electric vehicles, hybrid vehicles and batteries and connected vehicles. The Department's leadership in manufacturing continued in close partnership with industry, and continues today with emphases on sensing, diagnostics and manufacturing automation and micro- and nano-manufacturing.

A number of ME faculty took scholarly leaves to become involved in national policy through service to various government organizations. Ulsoy served as director of the Division of Civil and Mechanical Systems at NSF. Kota was assistant director for advanced manufacturing at the White House Office of Science and Technology Policy, and played a key role in launching the National Advanced Manufacturing Partnership and the Manufacturing Innovation Institutes. Albert Shih was Assistant Director for Technology at the NIST Advanced Manufacturing National Program Office of the National Institute of Standards and Technology (NIST). And in 2017, Dawn Tilbury was selected to serve as an NSF Assistant Director and lead the Directorate for Engineering.

The Department of Mechanical Engineering continues to be near the top of *U.S. News & World Report*'s annual rankings, as well as among the top 5 in the world by QS-World Universities.

RESEARCH AND EDUCATION

Research funding increased from about $20 million/year in 2000 to more than $35 million/year in 2015. Much of the increase has been associated with major research centers, including ARC, ERC/RMS, S. M. Wu Manufacturing Research Center and CLAIM, and new centers in advanced battery systems, robotics, clean energy, lightweight materials and socially engaged design. The Ground Robotics Reliability Center (GRRC) was established in 2007 with support from the U.S. Army TARDEC, with a focus on the reliability of unmanned ground vehicles.

Under the leadership of Steve Ceccio, the Naval Engineering Education Center was launched in 2009, to educate the next generation of naval systems engineers. A Department of Energy U.S.-China Clean Energy Research Center was established in 2010 under the leadership of Dennis Assanis; it continues under the directorship of Huei Peng. The Clean Vehicle Consortium focuses on disruptive technologies to improve fuel efficiency in vehicles. Another major center, established in 2014, is the American Lightweight Materials and Manufacturing Innovation Institute (ALMMII) under the leadership of Alan Taub.

ME established the Findley Learning Center (endowed by the family of former ME faculty member William M. Findley) as a dedicated space for student-instructor interaction. It has been so popular with students (who can find assistance with homework and exam preparation at the center virtually any time of the day) that it has now been adopted by other departments and is being expanded as part of renovations in GG Brown.

In 2000, the Department instituted the ME Graduate Symposium, where grad students can present their research in a relaxed environment. The symposium was expanded to include best presentation awards and poster sessions and became so popular it continues today as a College-wide event held every fall.

Under the leadership of Diann Brei, ME's associate chair for undergraduate education (2012-17), new initiatives were carried out to realize the vision of redefining mechanical engineering following the outcomes of the national 5xME workshops. ME's undergraduate curriculum has been revised to improve flexibility for students to explore disciplines outside engineering.

One of the additions to the curriculum was ME's Research, Innovation, Service and Entrepreneurship (RISE) program, which allows undergraduate students the opportunity to work alongside world-renowned faculty in state-of-the-art facilities on real-world projects that impact our society and future. The projects from the RISE program are then showcased in MEUS, the ME Undergraduate Symposium held at the end of each term.

Significant resources were also allocated to support undergraduate education in emerging new fields. For example, ME has embedded mechatronics into our Design and Manufacturing core curriculum, and nanoscale concepts were embedded in the senior lab core course (ME495) via leveraging upon atomic force microscope technology, introducing undergraduates to nanoscale phenomena in mechanics, biomechanics and heat transfer.

The Department began various international partnerships to provide global experiences for its students. In 2000, ME formed a strategic partnership with Shanghai Jiao Tong University (SJTU) to help reshape the way Chinese engineering colleges educated their students. SJTU used an ME model to restructure its undergraduate curriculum, and a pilot class of 60 students was admitted into the new program that same year as ME faculty members began their first set of lectures at SJTU. This effort, under the leadership of Jun Ni, has developed into one of the most successful international academic collaborations in the world and has resulted in the establishment of the UM-SJTU Joint Institute, with Jun Ni as its first dean.

In February 2001, ME signed a memorandum of understanding for a collaborative program with the mechanical engineering department of the Korean Advanced Institute of Science and Technology (KAIST). The agreement created a formal relationship between the two schools that included a plan to exchange students and faculty members for research and academic purposes of common interest.

Extracurricular activities continued to play a major role at ME, with nearly every student involved in project teams, industry internships or co-op experiences. The Better Living Using Engineering laboratory (BLUElab) provides engineering-based sustainability-related service opportunities for ME students. BLUElab activities include water accessibility, solar technology, resource management in homes, anaerobic digestion, engineering education and wind-powered technology. Each project team works with a partner community in Ann Arbor or Mexico, El Salvador, Guatemala, Jamaica, India or Nicaragua.

The Laboratory for Innovation in Global Health Technology (LIGHT) uses design ethnography techniques to co-creatively design and assess cost-effective technology solutions to healthcare challenges in low-income countries such as Ghana, Ethiopia and China.

And ME students and alumni helped bring the U-M solar car M-Pulse to victory in 2001 at the American Solar Challenge. M-Pulse was the third Wolverine winner (in addition to Sunrunner in 1990 and Maize & Blue in 1993) of six American Solar Challenge races. This success continued with first-place finishes by Momentum (2005), Continuum (2008), Infinium (2009), Quantum (2011) and Quantum II (2014) and placing 2nd in the world in the 2017 Bridgestone World Solar Challenge in Australia with their smallest car to date, Novum, giving ME nine national championships, six Top-3 World finishes and one International Championship.

FACILITIES

To meet the needs of the “new ME” in teaching and research, major improvements to the Department’s facilities were needed. This was advocated by several ME chairs (Papalambros, Ulsoy, Assanis, and Wang). From 2008 to 2017, three major facility projects were undertaken, planned, designed and constructed under the leadership of chair Kon-Well Wang and associate chairs Dawn Tilbury and Noel Perkins.

A new 62,880-square-foot world-class research complex, completed in 2014, with special facilities to support emerging areas. This $46-million addition to the GG Brown building was partially supported by a $9.5-million grant from NIST. At the core of the building, and resting on a separate and isolated foundation, lies an ultra-low vibration laboratory, which includes eight separate testing chambers with stringent control of vibration, temperature and humidity.

A separate renovation project costing $50 million, with $30 million from the state of Michigan, was launched upon the completion of the GG Brown addition in summer 2014. It improves the infrastructure of the building enormously, and, in addition, realizes a vision of a student-centric environment for teaching, learning and advising. The newly renovated space integrated many facilities in the central hub, including a large auditorium-style classroom, an advisee-friendly advising center, a modernized learning center for student-faculty interaction and expanded laboratory spaces for all the required Design & Manufacturing courses and instrumentation lab courses that support the “Design, Build, Test” pedagogical paradigm. The renovation project was completed in summer of 2016.

In 2017 an interior, as well as test cell retooling renovation of the Walter E. Lay Automotive Lab was completed. The project provided a much needed facelift to the interior of the Auto Lab, including updated offices, corridors and staircases, improved lighting and display areas, a new lounge and conference rooms, updated restrooms and an added lactation room, and HVAC and electrical upgrades.

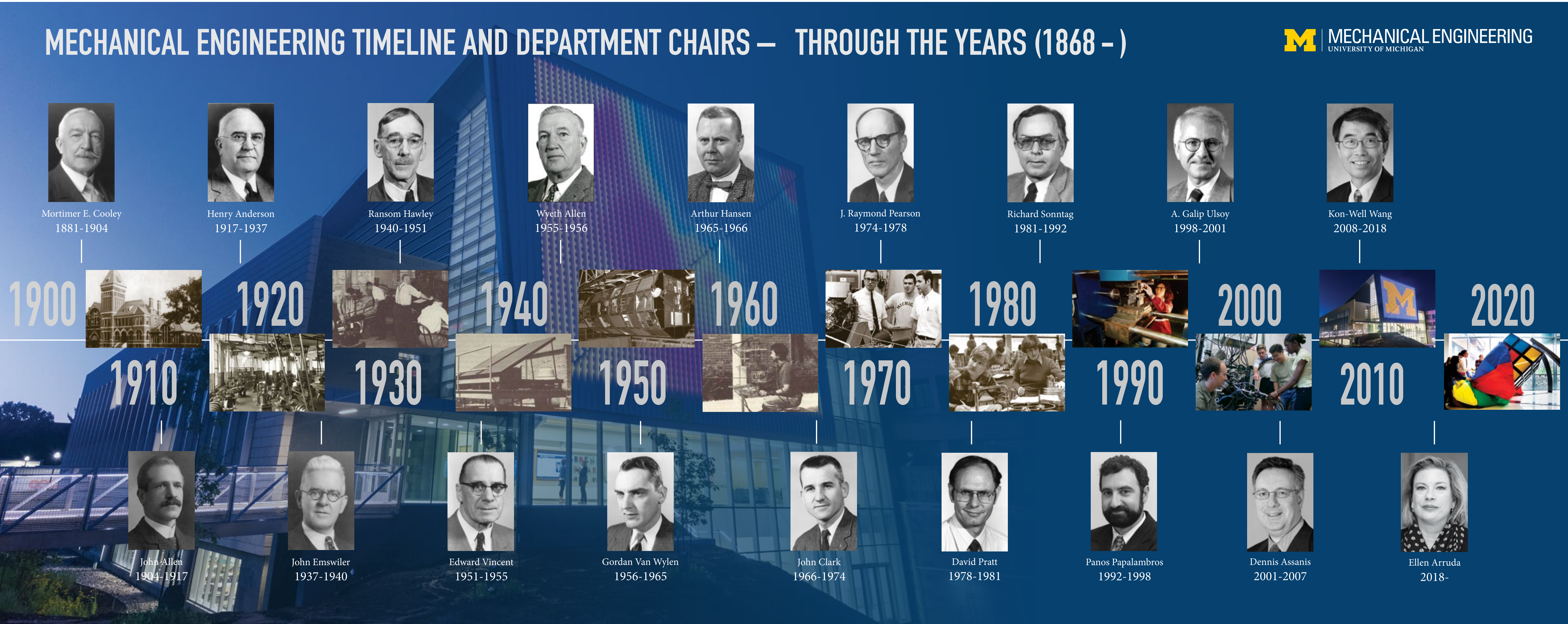
Another U-M facility with a strong connection with ME is Mcity, part of the Mobility Transformation Center (MTC). MTC, launched in 2013, is a partnership between U-M, the U.S. and Michigan Department of Transportation to dramatically improve the safety, sustainability and accessibility of the ways that people and goods move. The current director of the MTC is ME faculty Huei Peng. In 2016, Mcity, an MTC offspring, was launched. Mcity is a one-of-a-kind test site for connected and automated vehicles located at U-M's North Campus Research Complex. The test site has over 3,000 connected vehicles in Ann Arbor as well as instrumentation installed at most major intersections, used to collect traffic data. Mcity is the world's first connected and automated vehicle proving grounds, and will provide a unique resource for not only data collection, but for evaluation of vehicle connectivity and automation technologies in a controlled but realistic environment.

NATIONAL ACADEMY OF ENGINEERING AND DISTINGUISHED UNIVERSITY PROFESSORSHIPS

Seven ME core faculty members were inducted into the National Academy of Engineering (NAE): Yoram Koren, Galip Ulsoy, Dennis Assanis, Jyoti Mazumder, Jack Hu, Ellen Arruda and Noboru Kikuchi. Election to the NAE is among the highest professional distinctions accorded to an engineer. Three ME professors were recognized with Distinguished University Professorships, one of U-M's top honors: Galip Ulsoy, Yoram Koren and Panos Papalambros.

YORAM KOREN: A LEADER IN MANUFACTURING AUTOMATION

In 1980, Yoram Koren joined the Department as the Paul Goebel Visiting Professor, from the Technion in Haifa, Israel. He stayed until his retirement in 2014 as the James J. Duderstadt Distinguished University Professor of Manufacturing. Koren made many important contributions, including the first adaptively controlled machine tool, cross-coupled controllers for contouring and state modeling of tool wear and a virtual field methodology for obstacle avoidance in mobile robots. Most importantly, he is widely recognized as the founder of reconfigurable manufacturing systems (RMS). Koren was the director of the NSF-sponsored Engineering Research Center (ERC)/RMS, the first ERC at U-M and a massive research effort involving dozens of companies, dozens of faculty and hundreds of students. Koren's vision was to make manufacturing responsive to the changing needs of the consumer. Many of the technologies developed by the Engineering Research Center (ERC)/RMS researchers are in use in manufacturing plants around the world. Koren is among the most honored faculty in the history of the Department, winning numerous national and international awards, including election to the NAE and a Distinguished University Professorship.



NAE RECIPIENTS

Election to the National Academy of Engineering (NAE) is among the highest professional distinctions accorded to an engineer.

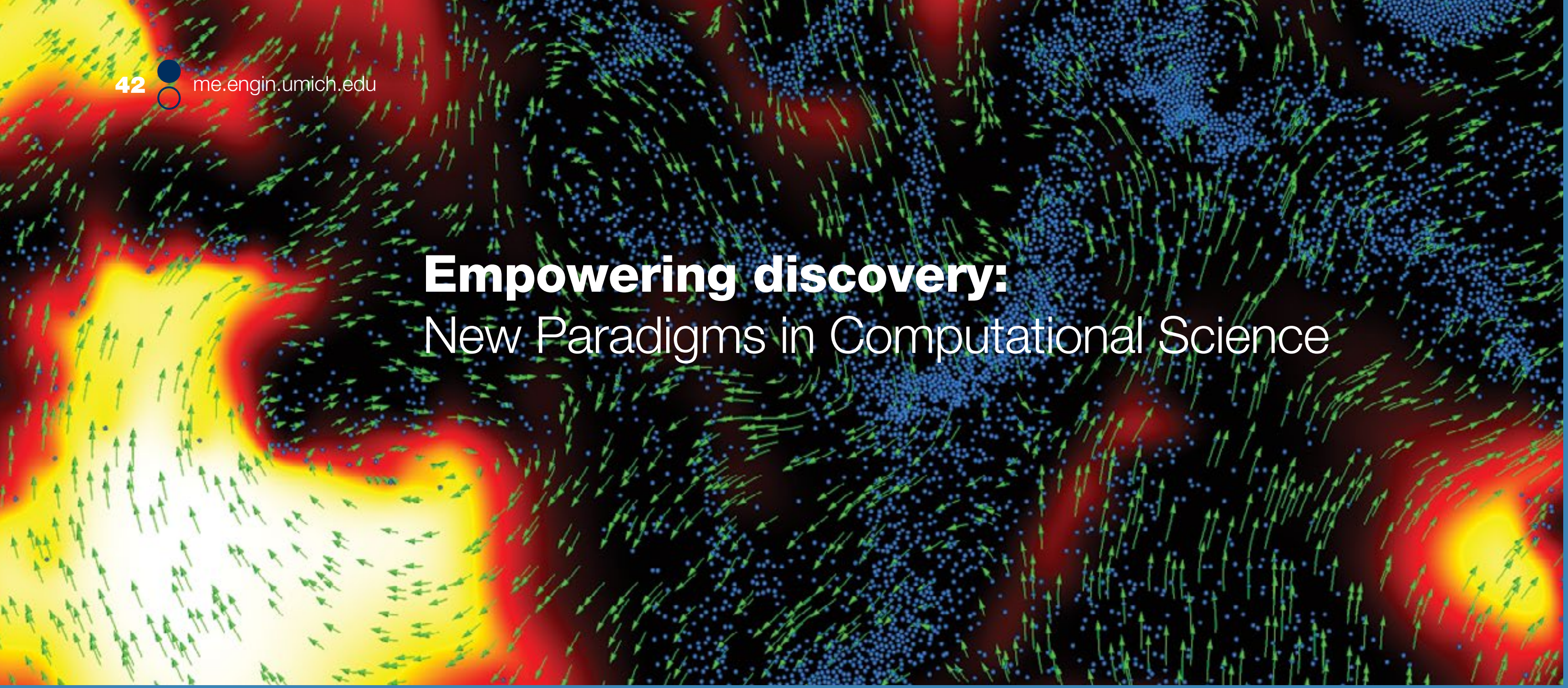
Chia-Shun Yih	1980
Albert Schultz	1993
Ronald Larsen	2003
Yoram Koren	2004
Steven Goldstein	2005
Alan Taub	2006
Galip Ulsoy	2006
Dennis Assanis	2008
Jyoti Mazumder	2012
Jack Hu	2016
Ellen Arruda	2017
Noboru Kikuchi	2017

NOBORU KIKUCHI: HOMOGENIZATION AND TOPOLOGY OPTIMIZATION

Noboru Kikuchi, the Roger L. McCarthy Professor of Mechanical Engineering, is an expert in computational mechanics, including the finite element method (FEM). He joined the Department in 1980 and worked on a variety of important research topics, including computational methods for contact problems, for adaptive mesh generation in FEM, and the homogenization method. That method, developed with Martin Bendsoe of the Technical University of Denmark, enabled not just the optimization of the dimensions of a given mechanical design, but the determination of the optimal topology itself from the loading and material properties. This field of topology optimization has had profound impact on the design of complex mechanical structures. Kikuchi collaborated with many colleagues, such as Sridhar Kota on design of compliant mechanisms, Panos Papalambros and Deba Dutta on rapid design and fabrication of parts designed using homogenization, and Jyoti Mazumder on additive manufacturing. Kikuchi's work is widely used in industry. He retired from the Department in 2015 and became president of the Central Research and Development Labs at Toyota Motor Company. He was elected to NAE in 2017.

U-M ME DOCTORAL STUDENTS (ABOVE FROM LEFT), WILL LEPAGE AND KAITLYN MALLETT, U-M TIM MAGANELLO/BORGWARNER DEPARTMENT CHAIR OF MECHANICAL ENGINEERING KON-WELL WANG, U-M ROBERT J. VLASIC DEAN OF ENGINEERING DAVID C. MUNSON, JR., STATE OF MICHIGAN GOVERNOR RICHARD D. SNYDER, U-M PRESIDENT MARK S. SCHLOSSER, AND NIST PROGRAM COORDINATION OFFICE DIRECTOR DR. JASON BOEHM AT THE DEDICATION OF THE NEW ME FACILITIES, OCTOBER 10, 2014.

A GIANT RUBIK'S CUBE (RIGHT) DESIGNED AND BUILT BY ME STUDENTS AND INSTALLED ON 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.



Empowering discovery:
New Paradigms in Computational Science

More than a dozen ME faculty are advancing their research through the recently established—and rapidly growing—Michigan Institute for Computational Discovery & Engineering (MICDE). ME Professor **Krishna Garikipati** directs the Institute, founded in 2013, as it carries out its mission to advance new paradigms of computational science, which cut across application domains, to enable innovations and discoveries that will define society for the next decade and beyond.

"We envision a future where computational science and engineering provide direct answers to the most pressing questions of the time," said Garikipati, whose own research spans biophysics, mathematical biology and materials physics.

ME associate professors **Vikram Gavini** and **Eric Johnsen** serve on the MICDE Management Committee, and Professor **S. Jack Hu**, also the University's Vice President for Research, serves on the MICDE Executive Committee. Across the University, more than 130 faculty are part of the MICDE, hailing from the College of Engineering; College of Literature, Science, and the Arts; Medical School and others. As of mid-2018, nearly $27 million in grant funding had flowed to the University from grants either initiated by, or having significant support from, MICDE.

A SHARED DISCIPLINE

MICDE grew out of the increasing use and recognition of computation as a pillar of science and a lens through which to focus and address both longstanding and emerging questions. The Institute's unique positioning opens up new investigative territory.

"The Institute occupies fertile ground that extends beyond the boundaries of traditional departments and colleges," Garikipati said. "By bringing computational methods to bear on any number of applications faculty are working on, computational science has emerged as a common discipline."

> [Our mission is to advance new paradigms of computational science, which cut across application domains, to enable innovations and discoveries that will define society for the next decade and beyond.]

Cross-cutting computational paradigms draw upon these limitless applications and, at the same time, provide an overarching framework through three centers within the Institute: the Center for Data-Driven Computational Physics, the Center for Network- and Storage-Enabled Collaborative Computational Science and the Center for Scientific Software Infrastructure.

Within each center, applications span a wide range. In the Center for Data-Driven Computational Physics, projects include climate modeling, cosmology and blood flow modeling for use in surgical planning. Projects in the Center for Scientific Software Infrastructure currently include disaster modeling and simulation and computational models of advanced battery materials.

The Institute also is bringing both established and emerging computational research into the classroom, with three new courses, several MOOCs (massively open online courses), a graduate certificate in computational discovery and engineering and a surge in students pursuing octoral degrees in scientific computing.

In addition to holding leadership positions, ME faculty are actively involved in MICDE projects. For the ME department, explained Garikipati, the Institute means two critically important things:

First, it provides an additional axis along which to strike up new collaborations. The Department's MICDE faculty come from all traditional ME application areas—solid and fluid mechanics, materials, thermal science, dynamics, design and manufacture—and they share a common appreciation of and expertise in computation and applied mathematics.

nearly **$27 million in grant funding** initiated by, or having significant support **from MICDE**

Second, the Institute allows the Department and its faculty to look five to 10 years into the future and, with computation as the vehicle, imagine where the ME methods of today can take engineered and natural systems. This future-focused process is behind the recent recruitment of **Xun (Ryan) Huan** to ME. Huan will begin his appointment as assistant professor in September 2018.

"We're thrilled to have Xun join the Department and the Institute," said Garikipati. "The position he was hired for was defined over a period of 18 months that included many conversations between ME leadership and MICDE, all shepherded by our ME MICDE faculty."

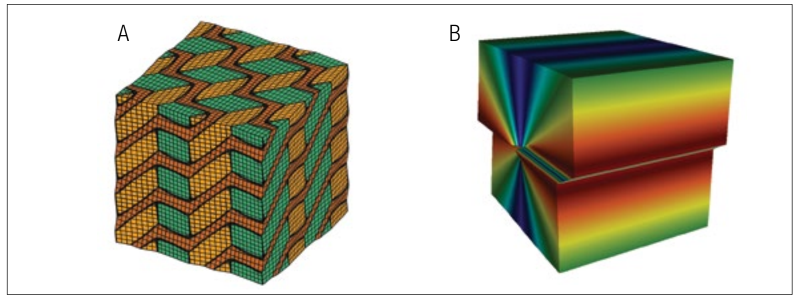
In addition to Garikipati, the Department's MICDE faculty include: **Rohini Bala Chandran** (computational heat transport), **Jesse Capecelatro** (computations on combustion in fluids), **Yue Fan** (computational materials science), **Vikram Gavini** (computational materials science), **Karl Grosh** (acoustics), **Xun Huan** (computational science), **Greg Hulbert** (computational dynamics), **Eric Johnsen** (computational fluid dynamics), **Wei Lu** (computational materials science), **David Remy** (computational dynamics and robotics), **Kazu Saitou** (computational design optimization), **Don Siegel** (computational materials science), **Steve Skerlos** (sustainable manufacturing) and **Angela Violi** (computations on combustion materials).

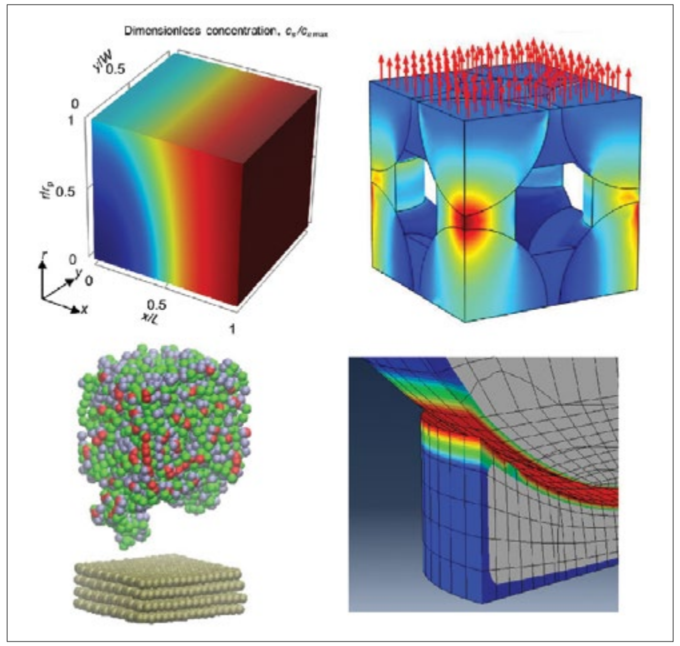
MICHIGAN INSTITUTE FOR COMPUTATIONAL DISCOVERY & ENGINEERING
UNIVERSITY OF MICHIGAN
micde.umich.edu

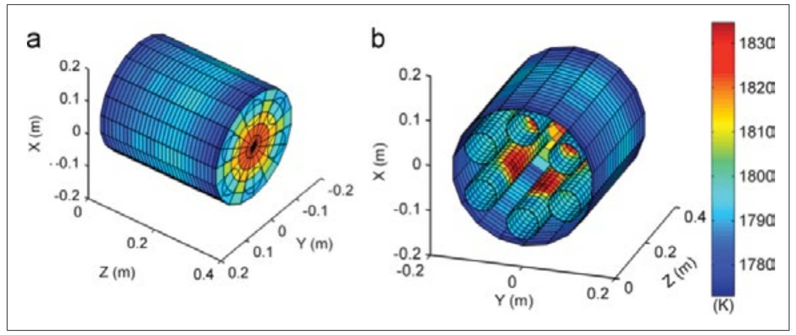
ME Assistant Professor **Rohini Bala Chandran** conducts research in the area of computational transport and kinetic modeling, integrated with experiments for energy and water applications. Her research group is interested in developing new computational tools to understand and evaluate radiative transport in flowing solid particles with applications for high-temperature thermal energy storage. Developing high-temperature thermal energy storage is crucial for integrating renewable energy sources with high-efficiency power cycles.

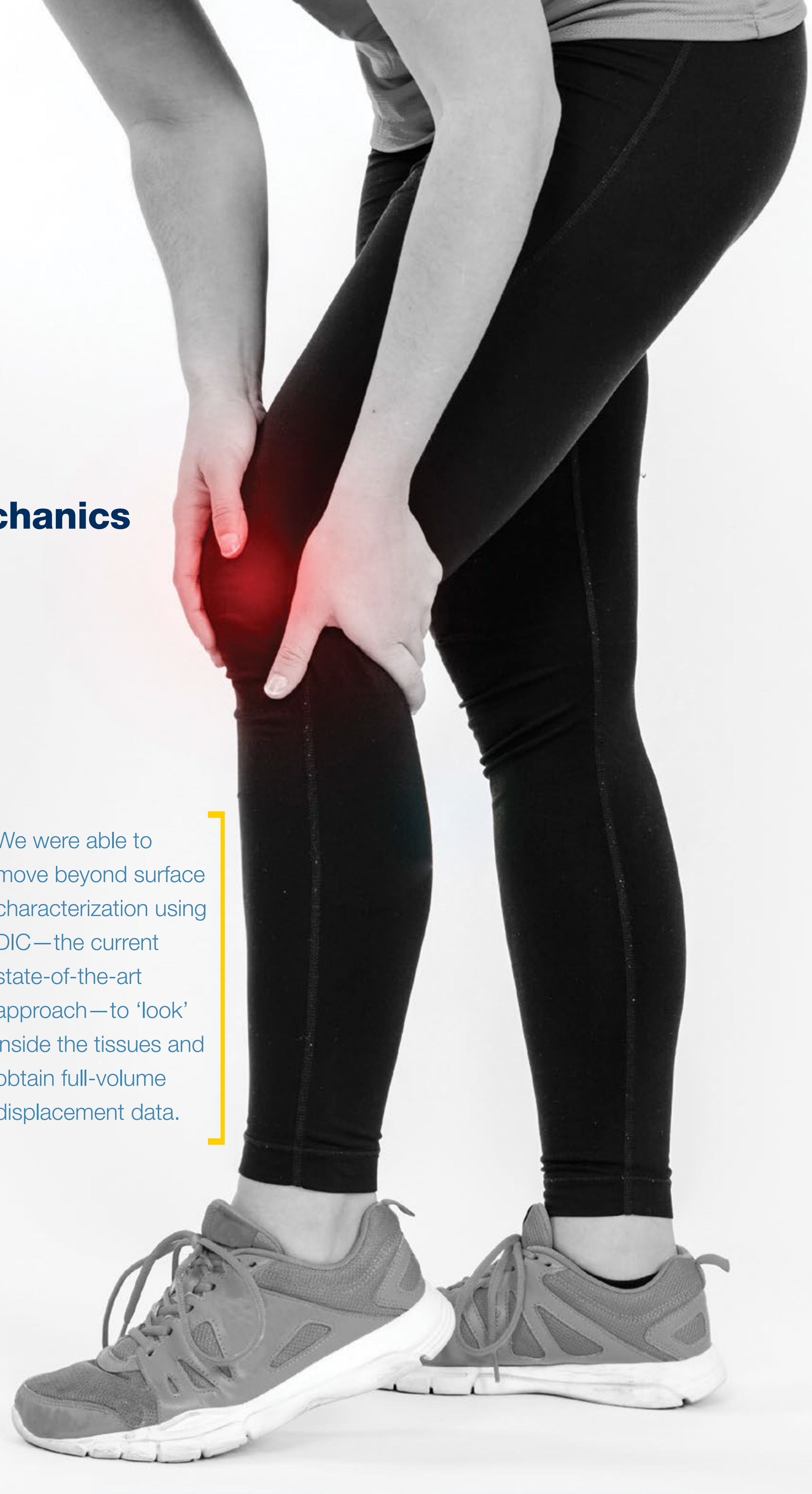
As a new faculty member at U-M, Bala Chandran benefits from MICDE's active engagement of the broader community of computational science researchers through the seminar series and the annual symposia. MICDE also promotes the computational interests of graduate students across a spectrum of engineering and science backgrounds through the Graduate Certificate in Computational Discovery & Engineering and fellowship opportunities. Bala Chandran's incoming graduate student, **Pratyush Agarwal**, will be using MICDE resources to provide fundamental heat-transfer insights of high-temperature thermal storage media and is excited to be part of the MICDE research community.

LEFT PAGE: Local temperature distribution in a turbulent gas-particle suspension. Sedimenting particles form clusters as a result of the fluid mechanics, which hinders heat transfer between the phases.
RIGHT PAGE, BOTTOM (L-R CLOCKWISE):
- Martensitic microstructures (A) and screw dislocation (B) computed with spline basis functions applied to high-order, nonlinear elasticity.
- Stresses in a battery electrode (top) and delamination of an active particle from the binder (bottom) from multi-scale, multi-physics simulations.
- Temperature distributions in a solar thermochemical reactor splitting carbon dioxide.









Modeling ACL Mechanics
to Prevent Injury

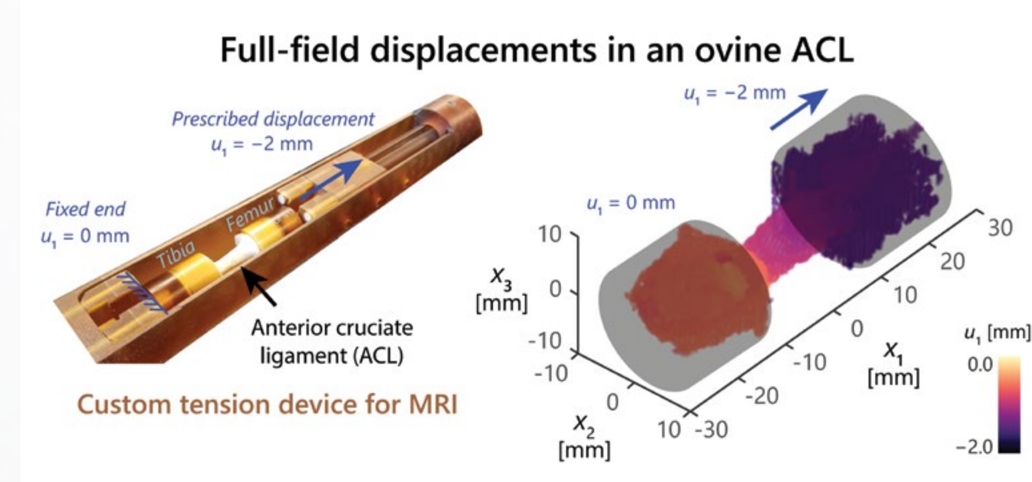
Each year, more than 200,000 injuries occur to the anterior cruciate ligament (ACL) of athletes and weekend warriors alike, with about half of those injuries leading to surgical repair since the ACL is critical to knee stability. The ligament is the most commonly injured soft tissue of the knee joint, and young women between the ages of 14 and 19, in particular, suffer the highest incidence of ACL tears.

"Unfortunately, when the ACL tears, it doesn't heal on its own," said **Ellen Arruda**, the Maria Comninou Collegiate Professor of Mechanical Engineering. Arruda heads the Soft Tissue Mechanics Laboratory at U-M.

In the case of tears, current clinical guidelines call for ACL reconstruction, using either cadaveric tissue from a donor or a ligament or tendon from elsewhere in the patient's own body. While Arruda noted that outcomes are generally good, both approaches leave room for improvement. Increased joint laxity and tears in the replacement tissue are not uncommon over time, and patients have about a threefold risk of developing osteoarthritis within a decade of the ACL injury.

"Understanding the mechanical properties of the ACL is so important for the design of future therapies and potential new clinical interventions, but it's also infamous for being difficult to model," Arruda said.

> We were able to move beyond surface characterization using DIC—the current state-of-the-art approach—to 'look' inside the tissues and obtain full-volume displacement data.



The structure of the ACL resembles fiber-reinforced composite, with collagen fibers aligned along the long axis of the ligament. In the physiologic state, two "bundles" of these fibers twist around each other. This is one of the factors that makes the ligament so challenging to characterize.

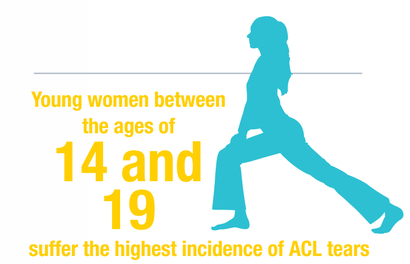
In work published in *Acta Biomaterialia* in 2017, Arruda and colleagues describe a non-contact, full-field displacement technique known as digital image correlation, or DIC, often used to study non-biologic materials. Only recently has it been applied to soft tissues. Her use of the technique overcame many of the challenges of conventional mechanical tests but still only obtained displacement field measurements on the outer surface of the ligament.

Building on that work, Arruda and collaborator Corey Neu, a professor at University of Colorado Boulder, coupled mechanical loading with magnetic resonance imaging (MRI) to conduct *in situ* characterization experiments to obtain the internal tissue displacement field information under applied loads.

But first, she and her research group had to design a loading device safe for an MRI scanner, which presented two major challenges. First, the loading device would have to be entirely non-metallic yet capable of actuation in order to be loaded. All electronic components would have to remain outside the magnet, and the device needed to be stiff enough to apply the required loads.

Second, the tissue would need to remain hydrated during the experiments, typically accomplished with a saline bath, but fluid leakage inside the magnet is problematic.

Arruda's device overcame both challenges. The load train comprised a long tube, with electronic components on one end and the specimen and grips on the other. To address the hydration issue, the team covered the experimental tissue in veterinary ophthalmic lubricant.



Once the team overcame these design challenges, it used particular magnetic resonance pulse sequences to gather data that could be translated into full-volume displacement fields.

"We were able to move beyond surface characterization using DIC—the current state-of-the-art approach—to 'look' inside the tissues and obtain full-volume displacement data," she said.

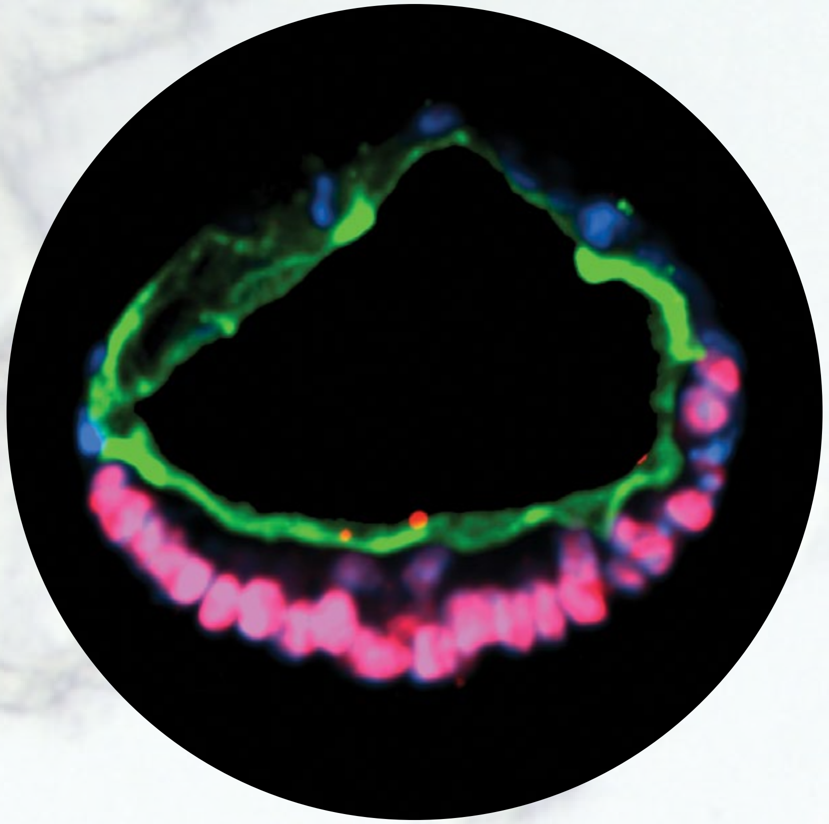
Preliminary data from the MRI technique, published in *Extreme Mechanics Letters* in 2018, closely match the data for the DIC technique. Arruda explained that the new data also provide greater information about the nonlinearity and anisotropy and even heterogeneity of the tissue. Together, the techniques enable greater understanding of tensile properties and development of more accurate stress-strain curves that, in contrast to previous techniques, take into account cross-wise and shear strain information in addition to axial strain.

The findings revealed that the ACL bundles are stiffer than previously believed and not as lossy, or viscoelastic. And since both methods provide actual tissue-level displacement information, they eliminated what was previously believed to be specimen-to-specimen variability in data.

"It was actually experimental uncertainty," Arruda said, "and, by homing in on what the tissue structure is in fact doing, our approaches virtually eliminate it."

Arruda is conducting further experiments to obtain more data over the full extension range of the ACL and, having demonstrated repeatability, is developing new mathematical models of tissue response. Those models can then be implemented into computational frameworks to conduct simulations of full-knee biomechanics and how various injuries to cartilage, the ACL or other soft tissues affect biomechanics and gait.

What's been missing from previous computational attempts to simulate knee biomechanics is accurate material models, Arruda explained. With such models underway, she is now looking ahead. "Imagine the young athlete who has a knee scan during her annual physical. With that scan we create a computational representation of her knees to simulate the biomechanics and asses her injury risk. One day we might be able to prevent some of these injuries in the first place."



Synthetic Models of Human Embryonic Development

When it comes to human development, our knowledge of the earliest stages of embryonic development—especially peri- and post-implantation in the maternal uterus—is sorely limited. Model systems that do exist center not on humans but on non-primate systems that differ markedly. Associate Professor **Jianping Fu**, who directs the Integrated Biosystems and Biomechanics Laboratory at U-M, is changing that.

In a series of papers published recently (*Nature Materials*, vol. 16, pages 419–425, 2017; *Nature Communications*, vol. 8, article number 208, 2017), Fu's research group has successfully developed novel synthetic embryological platforms that can open up previously inaccessible phases of human development to experimental study, helping advance human embryology and reproductive medicine.

Fu's research on modeling human development has laid the foundation for the emerging field of "synthetic embryo," which has been selected by the *MIT Technology Review* as "10 Breakthrough Technologies of 2018."

> Many compounds have unknown effects on pregnancy and human development, and our system is compatible with screening assays so it can help us identify them.

Fu's investigations into this emerging research area could be described as serendipitous. A few years ago, the lab of Dr. Deborah L. Gumucio, a professor in the Department of Cell and Developmental Biology, observed that human pluripotent stem cells (hPSCs), a stem cell type equivalent to embryonic cells in the implanting human embryo, possess intrinsic properties to form hollow structures with a central cavity or lumen. But how do hPSCs self-organize and form such three-dimensional structures? With Fu's longstanding interest in mechanobiology and hPSCs, he and Gumucio began to collaborate and study how different mechanical signals and forces might affect the function and behavior of hPSCs.

NOVEL MICROSCALE 3D CULTURE SYSTEM

The research team developed a bioengineered three-dimensional cell culture system that mimics the implantation environment with properly controlled mechanical properties. As in earlier observations, within one day, hPSCs formed hollow spheres. But soon after, hPSCs in the implantation-like culture environment began to look strikingly different from control cells cultured in standard culture: On one side of the hollow cyst, the cells appeared flattened and squamous, while on the other side they appeared columnar.

Given the embryonic origin and developmental potential of hPSCs, the research team decided to investigate in greater detail the identities of the columnar and squamous cells by comparing their molecular features with data in the scientific literature from other primates, since little to no human data exists. The team soon realized—with great excitement, Fu recalled—that what it was observing in the implantation-like culture was a self-organized asymmetrical embryonic structure, containing columnar pluripotent epiblast cells on one side and flattened, squamous amniotic cells on the other. *In vivo*, the epiblast or the embryonic disc would eventually develop into the fetus, while the amniotic cells would eventually develop into the amnion, the fluid-filled membrane sac in which the embryos develop.

The team has thus demonstrated for the first time that without maternal or extraembryonic tissues, hPSCs can self-organize into an asymmetric structure with amnion-epiblast patterning that resembles the core of the implanting human embryo. The researchers refer to the asymmetrical tissue as PASE, post-implantation amniotic sac embryoid.

CONTROLLING THE PROCESS USING MICROFLUIDICS

The team further identified the involvement of signaling molecules, bone morphogenic proteins (BMPs), in driving amniotic differentiation of hPSCs. To further control symmetry breaking of hPSC cysts, Fu and his co-workers developed a microfluidic system to expose half of the hPSC cysts to BMP stimulation. The cells exposed to BMP differentiated; the cells not exposed retained pluripotency and remained as the epiblast.

FUNDAMENTAL SCIENCE AND FIRST APPLICATIONS

Fu and collaborators already have begun investigating fundamental questions that underlie the symmetry-breaking process. What are the signals that trigger the symmetry-breaking process? How is the tissue boundary between the amnion and the epiblast determined and maintained?

The group also is investigating the role of the amnion in controlling further embryonic development, including into the embryonic disc.

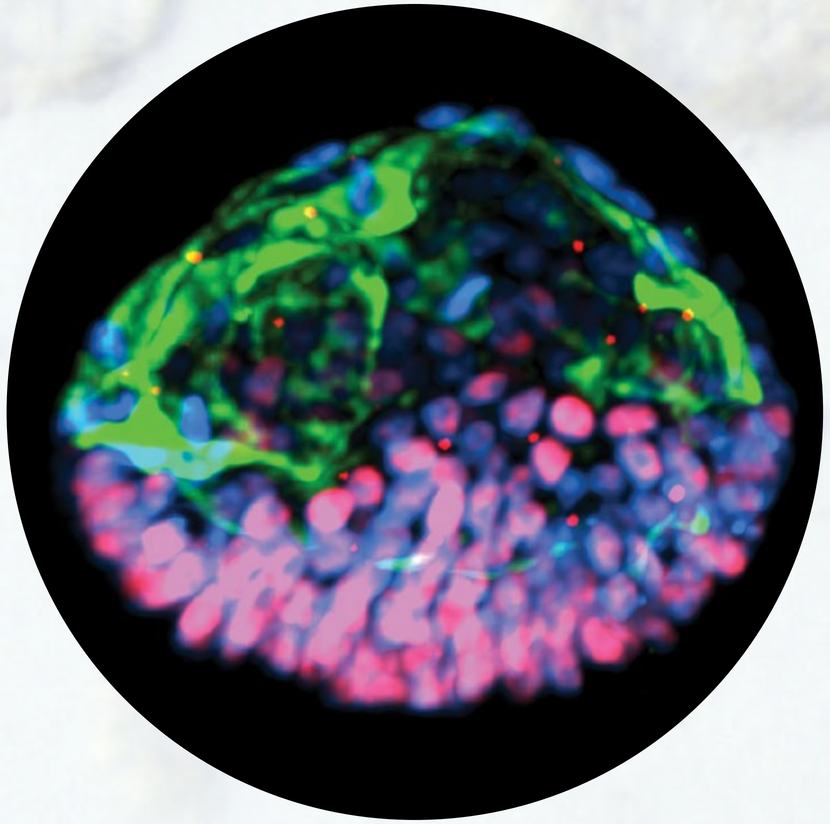
"We already know from follow-up studies that the amnion serves as a signaling center and triggers continuous development," Fu said. "These are incredibly intricate intercellular interactions among the amniotic cells and between the amnion and the epiblast, and we need to better understand the amnion's functional role."

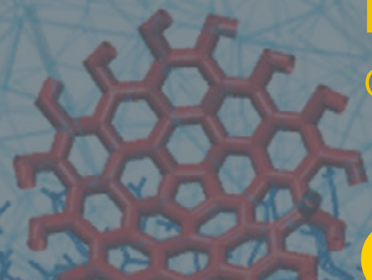
The microfluidic device Fu's team developed now is also about to be used to screen for drug toxicity and prenatal formation of birth defects, or teratogenesis. "Many compounds have unknown effects on pregnancy and human development, and our system is compatible with screening assays so it can help us identify them," he said.

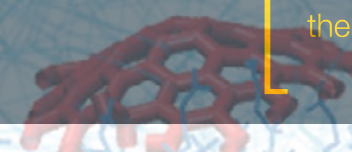
"I should stress that we're not trying to grow a complete embryo," Fu added. "Our goal is to leverage our synthetic models to advance fundamental understanding of human development, which remains largely mysterious. Such efforts will be valuable for preventing pregnancy loss, birth defects and teratogenesis and improving stem cell-based research and therapies. There are many important questions about human development that we can study in the near future. I am very excited."

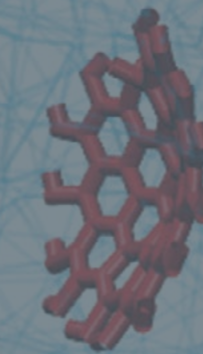
BACKGROUND IMAGE: Bright field image showing many individual cysts containing central cavities developed in 3D culture from human embryonic stem cells. Note that most cysts have uniformly squamous morphology. All cells contained in these cysts are amnion cells. The one cyst at the center (above), shows an asymmetrical morphology, with one side squamous (the amnion) and the other side columnar (the epiblast). The cavities in all cysts are the pro-amniotic cavity.

CIRCULAR IMAGES: Immunofluorescence images showing an asymmetrical cyst, with the columnar side (the epiblast) stained positive for OCT4 (pink; pluripotency marker), and the squamous side (the amnion) negative for OCT4. The green fluorescence is from staining for some central cavity marker.



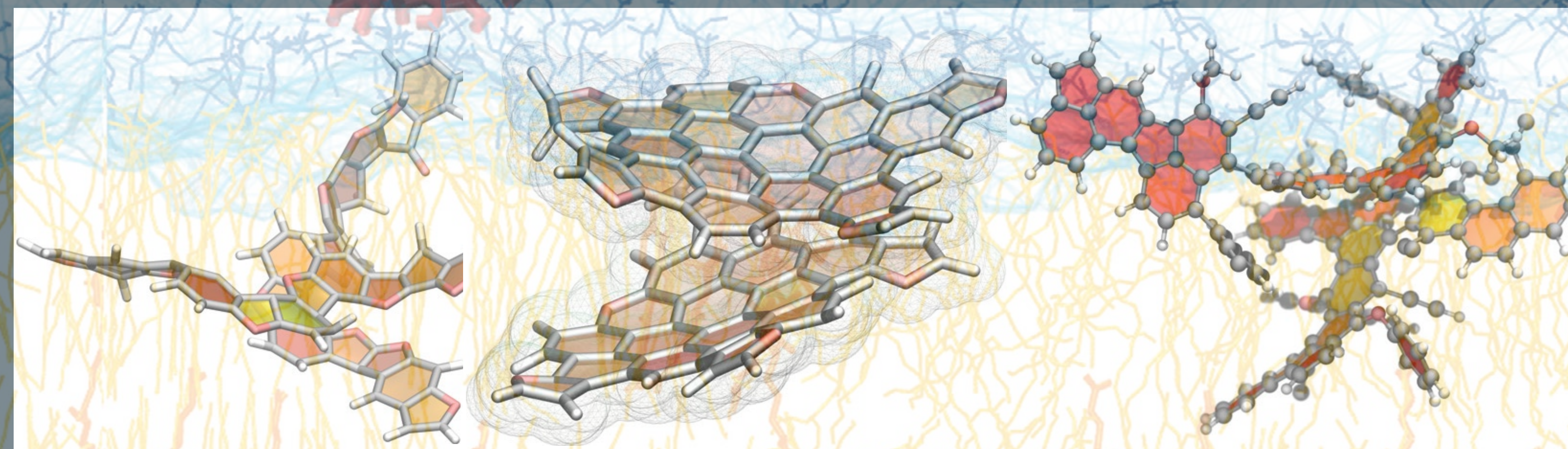






Formation and Health Effects of Nanoparticles in the Environment

Although the particles readily pass into the membrane, our work showed it's not likely the clusters separate once inside it.

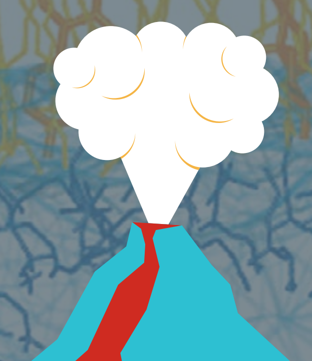


Combustion from common processes—for example forest fires, volcanic eruptions, cigarette smoking and waste incineration—lead to the formation of various pollutants. These range from small polycyclic aromatic hydrocarbons, such as naphthalene and anthracene, to nanoparticles and soot.

In recent work, Professor **Angela Violi** and her team at U-M have used *ab initio* and probabilistic computational techniques, including the Stochastic NAnoParticle Simulator (SNapS) software, to study the formation of hydrocarbons in flames and discovered, for the first time, the formation of furans when hydrocarbon fuels are burned. Working with experimental groups at Stanford University, Sandia National Laboratories and Lawrence Berkeley National Laboratory, the team has reported on the formation of about 100 oxygenated compounds previously unaccounted for.

"Although these compounds are toxic and can have negative effects on air quality and climate, no one has observed large furans and related oxygenated hydrocarbons in actual flames, so how they form and behave wasn't well understood," said Violi, whose work focuses on computation and modeling of nanoparticle formation and their interactions with biological systems.

The study has implications for future models of fuel combustion that will need to include these new species. The findings also highlight the importance of oxidation chemistry to control emissions of toxic and carcinogenic combustion byproducts that also affect global warming. For example, emissions of particles and soot could be minimized by adding an oxygen-rich post-combustion zone at an elevated temperature that could be kept below the threshold for the formation of nitrogen oxides. Furans could be removed through carbon monoxide reactions, identified by the SNapS simulations.



Combustion from from **mobile sources, power plants, open fires, cigarette smoking and waste incineration lead to the formation of various pollutants.**

HOW NANOPARTICLES INTERACT WITH CELL MEMBRANES

From consumer products and medical devices to vehicle and industrial emissions, nanomaterials are making their way into our everyday lives. When compared with larger particle sizes of the same materials, nanoparticles have a larger ratio of surface area to volume and may interact with cells and organisms in different ways than their bulk counterparts.

But research to date has been limited for many reasons, including myriad factors that influence how the particles interact with the cell wall, the lipid membrane that acts as the boundary between the intracellular and outside worlds.

"Just about every aspect of the nanoparticle, from composition and surface chemistry to shape and charge, influence these interactions, so gaining a holistic understanding of what's happening has been challenging," Violi said.

With colleagues at the U-M School of Public Health and the University of Southampton in the United Kingdom, Violi's research group was the first to combine biophysical, biochemical and computational methods to learn how a particular nanoparticle, C60, also known as a fullerene, get transported into living immune cells.

The team discovered that C60 indeed enters cells and that the predominant way is passive diffusion through the lipid membrane, rather than actively by endocytosis, a process by which the cell actively engulfs a particle to transport it inside.

Computational models and molecular dynamics simulations also predicted that low concentrations of nanoparticles enter the membrane one at a time or in pairs and cause little disturbance. But at higher concentrations, clusters enter the cell wall and cause the membrane to deform or bulge. Imaging using nuclear magnetic resonance of membrane models supported the computational findings.

Further, the team used molecular dynamics simulations to learn whether and, if so, how the clusters of nanoparticles disbanded. "Although the particles readily pass into the membrane, our work showed it's not likely the clusters separate once inside it," Violi noted.

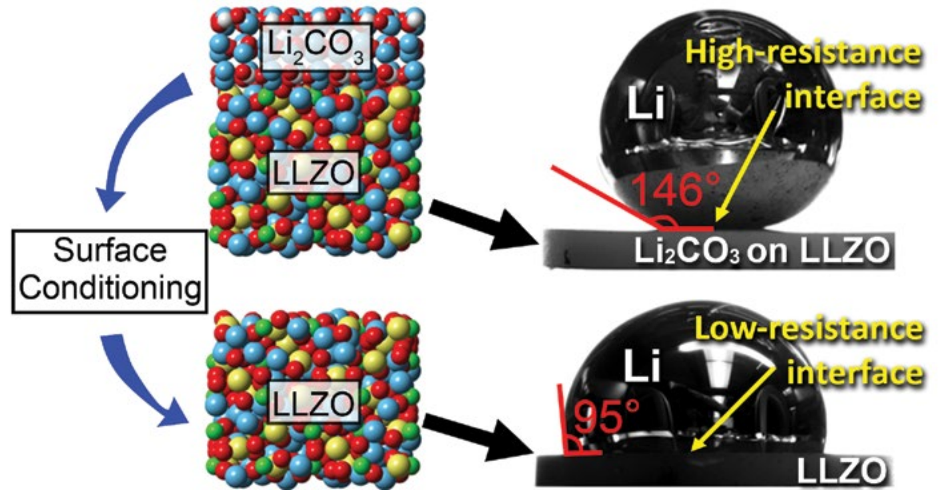
Overall, the experimental results closely aligned with the team's models. Going forward, a key question remains: Precisely how the fullerenes travel from the cellular membrane into the cell's cytoplasm.

The results will guide further investigations into the particular molecular pathways involved. "Our goal," said Violi, "is to enable expanded models that can be used to predict the uptake of these nanoparticles and at the same time to control the interactions between nanoparticles and living cells by fine-tuning their physical and chemical characteristics."

BACKGROUND IMAGE: Biological Membrane Simulations.

TOP LEFT, MIDDLE: Representative soot precursor molecules produced in an etylene/air.

TOP RIGHT: Soot precursor formed in IC engine conditions.



> We eliminated resistance with persistence. Through systematic experimental and theoretical studies we developed a process to achieve solid electrode-solid electrolyte interface resistance lower than what is observed in liquid-based Li-ion batteries.

Advanced Solid-state Batteries
to Speed Vehicle Electrification

A major roadblock to vehicle electrification, and to the transition from fossil fuels to renewable energy, is energy storage. Better batteries are needed if the shift from internal combustion engines to electric powertrains is to become a reality.

"It's the battery that's holding back the transition," said associate professor **Jeff Sakamoto**. "If we're serious about widespread vehicle electrification, we need to develop a better one."

Sakamoto and others want to see improvements in three key areas: cost, performance and safety. When it comes to performance, defined in terms of energy density, today's lithium-ion batteries are reaching their thermodynamic limits at about 600 watt-hours per liter. And the liquid electrolyte that shuttles ions between the anode and cathode in today's Li-ion batteries is flammable, causing fires in some circumstances.

All three factors could be improved significantly by replacing the liquid electrolyte with a solid, and Sakamoto is one of the first researchers to investigate the use of a fast-ion conducting oxide based on the atomic structure of the mineral garnet. In work published in *Solid State Ionics* in 2012, Sakamoto's group and Dr. Jeff Wolfenstine at the Army Research Lab discovered how to control the atomic placement in synthetic garnet to achieve high ionic conductivity and stability. The new garnet formula consists of lithium, lanthanum and zirconium oxide (LLZO).

The use of LLZO as a solid electrolyte can pave the way for using what he describes as the "holy grail of electrodes": metallic Li. The negatively charged anode in a typical Li-ion battery is made of carbon, in the form of graphite, and replacing the carbon with metallic Li could reduce the cell volume by half, thereby enabling energy density to double to about 1,200 watt-hours per liter.

"LLZO is an outlier," said Sakamoto. "It's anomalous among solid-state ion conductors in that it's stable against metallic lithium."

> Better batteries are needed if the shift from **internal combustion engines to electric powertrains** is to become a reality

And not only that: Sakamoto has shown that LLZO can conduct ions faster than liquid electrolyte membranes—and at room temperature. "It's one of the few materials that exhibits both of those properties," he said.

Along with the advances, some important challenges remain, including better understanding the dynamics at the interfaces among components and reducing resistance between the metallic lithium electrode and the solid electrolyte. Transitioning to solid-state batteries requires ions and electrons to move through battery components as quickly and easily as they do in conventional liquid-based batteries. This has been a major challenge.

Recently, Sakamoto and ME colleagues **Neil Dasgupta**, assistant professor, and **Don Siegel**, associate professor, have characterized the impact of surface chemistry on resistance and demonstrated a straightforward heat treatment process that can better prepare the LLZO surface to reduce resistance at the interfaces and improve bonding. Their process brings resistance down to two ohms per square centimeter—less than the resistance encountered with state-of-the-art Li-ion electrodes with liquid electrolytes—and maintains that low level over hundreds of cycles.

Although metallic Li isn't combustible, it is highly reactive with air and water. To what extent isn't fully clear yet, and Sakamoto is conducting ongoing work to quantify the risk.

The advanced solid-state battery work is receiving widespread attention. In May of 2017, Sakamoto appeared on the Public Broadcasting Service program *NOVA* during an episode entitled "Search for the Super Battery." The work with Dasgupta and Siegel to achieve higher charge rates with a solid electrolyte was featured in the U.S. Department of Energy (DoE) U.S. DRIVE 2017 Technical Accomplishments Report.

The three investigators also participated in a DoE workshop on Electrochemical Energy Basic Research Needs. Sakamoto served as panel lead for Solid-State and Semi-Solid Electrochemical Energy Storage. The work done at U-M was featured on the cover of the resulting report, which outlined priority research directions for the United States over the next decade.

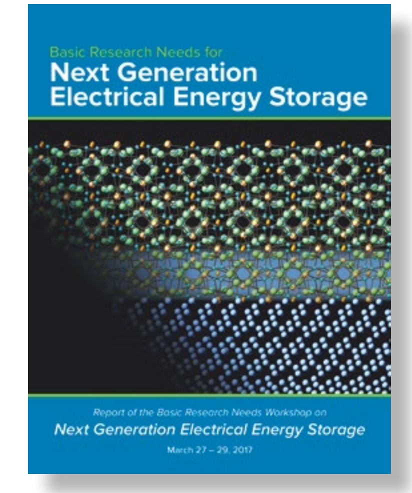
The trio collaborates frequently now, with Siegel's work in computation and computational theory and Dasgupta's work in atomic layer deposition and in situ cell visualization complementing Sakamoto's expertise in materials design and discovery. The joint research is both fundamental and applied, requiring multiple theoretical and experimental techniques at multiple length scales to better understand the interface dynamics of solid-state energy storage devices.

Given the ME department's 150th anniversary, Sakamoto is contemplating how this solid-state battery work might look in 50 years, at the time of the Department's 200th anniversary.

"Fifty years from now, I think we'll look back and see that the first application of solid-state battery technology will power vehicles and devices in extreme or hot environments such as on the surface of Venus—today, I think we could be about 10 years from the launch pad," said Sakamoto, whose extensive energy storage expertise includes work at NASA's Jet Propulsion Laboratory on the batteries of the twin 2003 Mars Rovers.

From there, he envisions that the ceramic technology might branch off into new technologies for separation, in particular to separate Li from other alkaline metals with which it often occurs. As the technology further evolves, Sakamoto expects to see more familiar applications—mobile phone batteries, electric vehicles and perhaps large-scale grid storage.

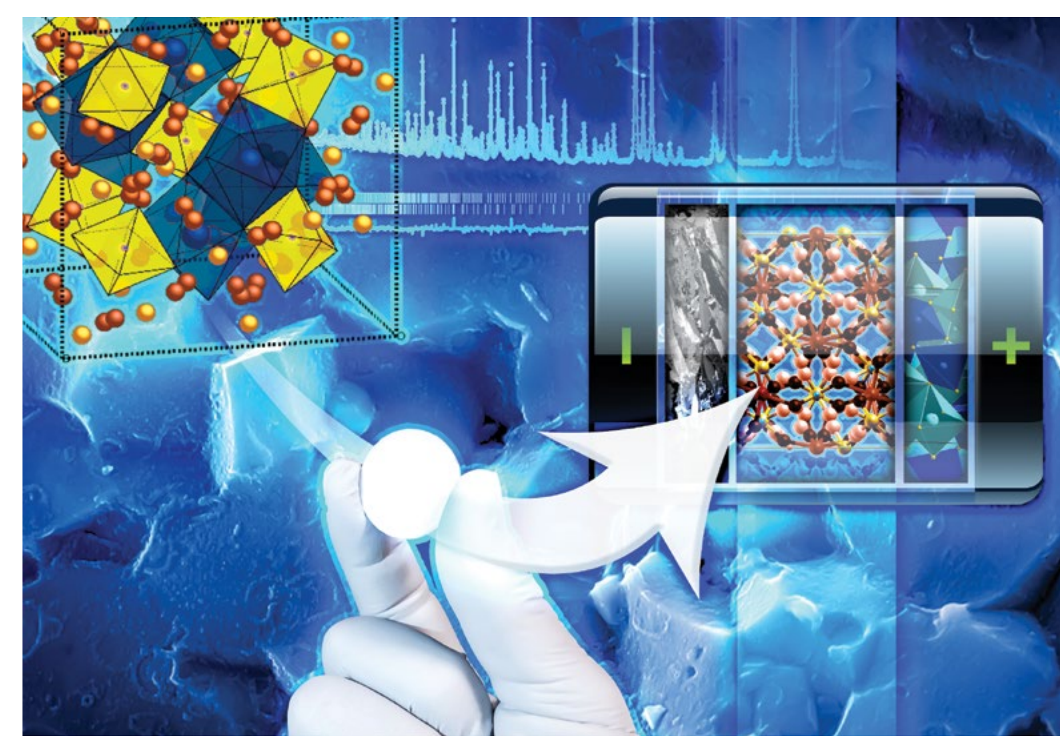
"It's such a unique platform for multidisciplinary science and engineering," he said. "At the leading edge is the most interesting place to be—there are still so many physical and electrochemical phenomena we don't understand."



TOP LEFT: Illustration of the breakthrough found in lowering interface resistance between solid lithium electrodes and the solid garnet electrolyte.

TOP RIGHT: This DOE report provides suggested areas of research over the next decade.

LOWER RIGHT: A portion of the cover art from *Advanced Energy Materials* publication depicting the microstructure and neutron diffraction pattern (background) and the crystal structure and an image of an electrolyte membrane and solid state battery schematic (foreground).



Can Thin Air Power a Car?

The advent of connected autonomous vehicles, or CAVs, is making the concept a reality

The day when drivers can use thin air—or, rather, the information transmitted through it—to "power" their cars is not far off.

Twenty years ago, the idea of moving a vehicle with air might have seemed preposterous. But the advent of connected autonomous vehicles, or CAVs, is making the concept reality. Leveraging connected information streams to enable a car to use less fossil fuel could have a tremendous impact on the health and prosperity of society in addition to reducing traffic accidents and congestion.

The day when drivers can use thin air—or, rather, the information transmitted through it—to "power" their cars is not far off.

"The ME department has always been at the forefront of automotive powertrain control, pushing every limit in fuel consumption and emissions minimization, so it's not surprising this vision is being realized here," said Professor **Anna Stefanopoulou**, who was one of three ME professors selected to develop the NEXTCAR, or Next-Generation Energy Technologies for Connected and Automated on-Road Vehicles. The goal of the initiative, funded by the U.S. Department of Energy Advanced Research Projects Agency-Energy (ARPA-E), is to develop technology that delivers energy savings of more than 20 percent over the course of a vehicle's trip.

Stefanopoulou joined forces with the Southwest Research Institute and Toyota Motor North America to optimize the vehicle's speed and the battery-fuel power split of a Prius Prime plug-in hybrid electric vehicle (PHEV). The team has chosen to conduct testing with a 2017 model, already renowned for its exceptional fuel and energy efficiency of 54 mpg in the hybrid mode.

Using vehicle-to-infrastructure (V2X) information, optimal control algorithms can help a vehicle plan its acceleration and use of its battery power wisely, stretching its resources instead of relying on traditional charge-depleting and charge-sustaining strategies of non-connected vehicles. The researchers aim to operate within the processing capability of production microcontrollers. An initial phase of the project will deliver a driver advisory system. The final phase will focus on full autonomy.

ME Professor **Jing Sun** also formed a NEXTCAR team with ME Assistant Research Scientist **Ding Zhao**, Professor **Ilya Kolmanovsky** of Aerospace Engineering and Assistant Research Scientist **Yiheng Feng** from the U-M Transportation Research Institute along with experts from San Diego State University and Pacific Northwest National Laboratory. Their work focuses on forecasting the traffic environment with transportation analytics, optimizing vehicle speed and thermal load profiles with V2X and coordinating power and thermal management with intelligent algorithms that continuously adapt system operation. The team is working toward delivering an integrated solution by establishing models, design processes and tools as well as developing control and optimization algorithms and demonstrating the technology in simulations, hardware-in-the-loop and vehicle experiments.

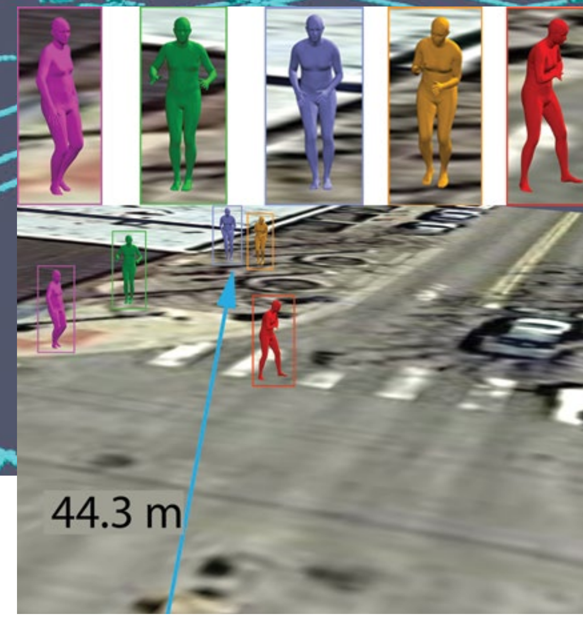
ME Professor **Huei Peng** is co-principal investigator of another team, led by the University of Delaware and working with researchers from Boston University, Oak Ridge National Laboratory and Bosch. This team focuses on improving the fuel consumption of an Audi A3 PHEV. A two-level optimization approach has been adopted: the supervisory and vehicle dynamics controllers perform higher-level optimization, for example eco-routing and coordinated adaptive cruise control to determine the best route to take and the corresponding vehicle speed profile. The powertrain (PT) controller manipulates the engine, battery and transmission control in coordination with this higher level control. Field testing will start later in 2018, at the U-M Mcity Test Facility.

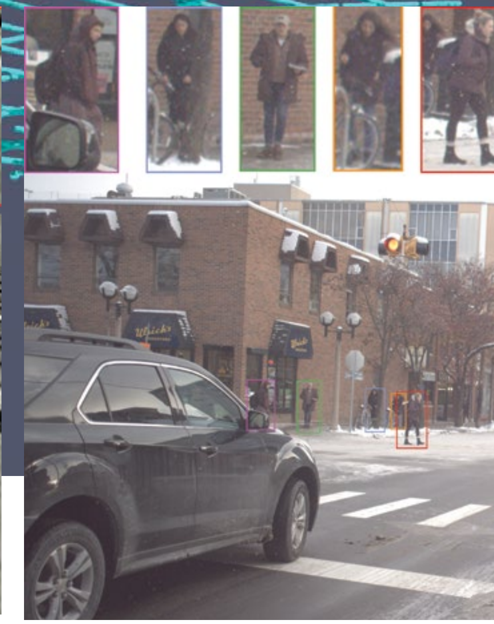
Stefanopoulou and her students—and the other ME faculty and their teams—are all collaborating, sharing resources and knowledge despite working on competing teams. In fact, the principal investigators of two additional teams are former ME students who are now professors at other universities. That brings the count of highly competitive ARPA-E NEXTCAR teams with deep (blue) roots in U-M ME to five of the 11 funded.

IMAGE: Department Chair and Michael G. Parsons Collegiate Professor of Naval Architecture and Marine Engineering Jing Sun, William Clay Ford Professor of Manufacturing Anna Stefanopoulou, Roger L. McCarthy Professor of Mechanical Engineering Huei Peng and Aerospace Engineering Professor Ilya Kolmanovsky.

Seeing the World Around Them:

Ensuring the Safety of Autonomous Vehicles





BACKGROUND IMAGE: A lidar-segment.
TOP TWO LEFT: Illustrating a computer-simulation of a pedestrian crossing.
TOP RIGHT: Various simulations of pedestrian traffic.
LOWER LEFT: Left Image -> Camera Observation and Ours -> Estimated Body Pose.
LOWER RIGHT: Time-synced stereo images.

In spite of rapid advances, many technical hurdles remain when it comes to the safe deployment of autonomous vehicles. And as we move toward greater deployment, researchers also need to look at larger and related trends and issues. As U.S. vehicle ownership rates fall and adoption of self-driving cars and on-demand and ride-sharing applications rise, the vehicle of the not-too-distant-future may function more as a personal robotics system rather than a conventional car.

Along the broad spectrum of potential uses, how will such systems be controlled to ensure safety as they carry out an increasingly wide range of activities? Assistant professor **Ram Vasudevan**, co-director of U-M's Ford Center for Autonomous Vehicles (FCAV), is investigating how autonomous systems learn and plan in order to offer new insights.

For the safe operation of autonomous vehicles, driverless cars must "learn" how to mimic what human drivers do intuitively. Arrive at a corner and see a pedestrian with a hand up approaching the crosswalk—is the individual telling you to stop or waving to someone across the street? Is the person about to step into the road or are they waiting for a light to change?

Estimating poses and drawing accurate conclusions from them is not a new challenge for mobile robotics systems. "The state of the art for some time now has been to use datasets built upon manually labeled, two-dimensional images from conventional motion capture systems," said Vasudevan.

Vasudevan used 2 sets of stereo cameras that captured more than 5,000 pairs of high-resolution images

Recently, deep learning or deep neural networks have been used to address the three-dimensional pose-estimation problem, but collecting ample data for training and validation has been difficult, and the conventional motion capture systems that gather such data limit the complexity and diversity of the scenarios that can be represented.

"There's been a real bottleneck when it comes to capturing realistic, in-the-wild scenarios with multiple individuals, obstacles and other dynamic factors," said Vasudevan, who has created the first large-scale dataset of pedestrians at realistically complex urban intersections with accurate and reliable 3D annotations.

To create the dataset, known as PedX, without relying on motion capture, Vasudevan used two sets of stereo cameras that captured more than 5,000 pairs of high-resolution images, then annotated them with manual 2D and 3D labels. The labels took the form of mesh models for each individual pedestrian and were situated in real-world metric space and overlaid with LiDAR (LIght Detection and Ranging) data. At the same time, the researchers used a motion capture system to establish ground truth and ensure that data collected aligned with the real-world circumstances.

"We set out to tackle the pose-estimation problem not only in 2D but realistically, *in situ*, in 3D," said Vasudevan. "It's not enough for an autonomous vehicle to recognize an outline in the shape of a box that represents a human—to navigate their environment safely, self-driving systems need to 'see' everything in their surroundings in three dimensions."

The research team methodically validated the process and found that the automated method generates reliable 3D models that can replace manually annotated 2D labels without sacrificing accuracy. Working at a distance of 40 meters, the new method produced models that were accurate within 10 to 15 centimeters—"more accurate than humans," Vasudevan said.

Now publicly available, the PedX dataset is the first based on realistic urban intersections, which include multiple and interacting individuals, individuals carrying objects, vehicles and a variety of weather conditions. Not only does it help solve the 3D pose-estimation problem but also can help address additional problems, such as determining priority at intersections and predicting pedestrian trajectories.

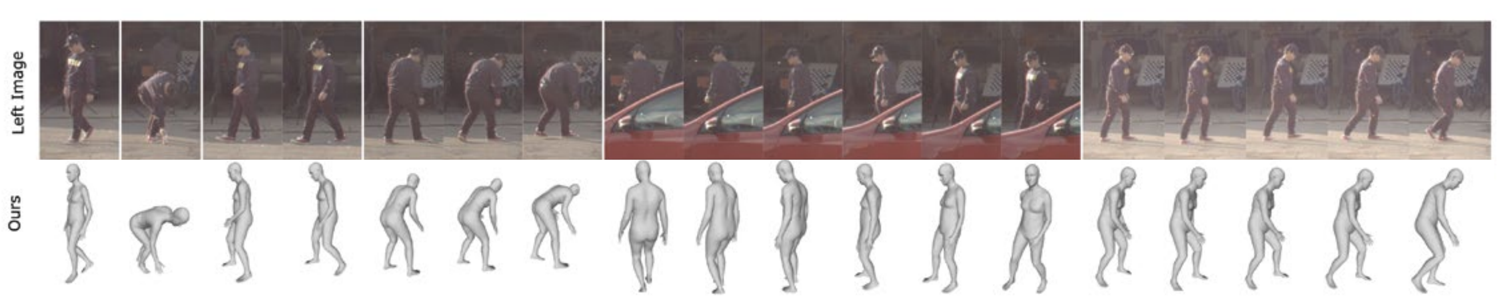
> There's been a real bottleneck when it comes to capturing realistic, in-the-wild scenarios with multiple individuals, obstacles and other dynamic factors.

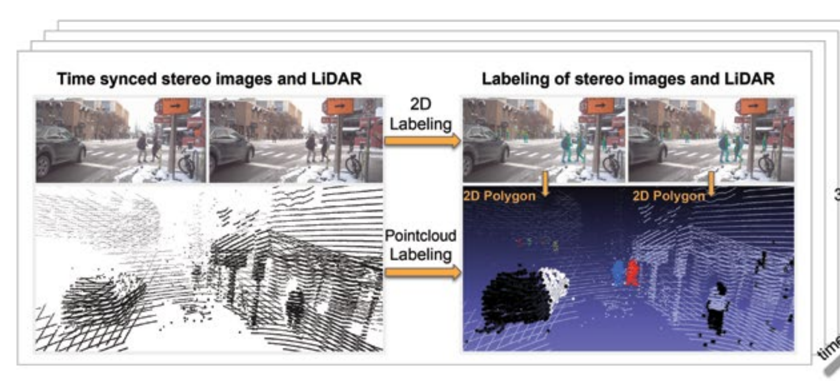
In addition, Vasudevan and his team have developed a novel technique to leverage these estimations of a pedestrian's pose along with contextual information about the urban environment to accurately predict the location of a detected pedestrian in real time. This research, which was published in *IEEE Robotics and Automation Letters* in 2017, showed that incorporating estimates of a human's pose can improve the quality of predictions of the future location of a pedestrian, which can drastically improve the safety of autonomous vehicles.

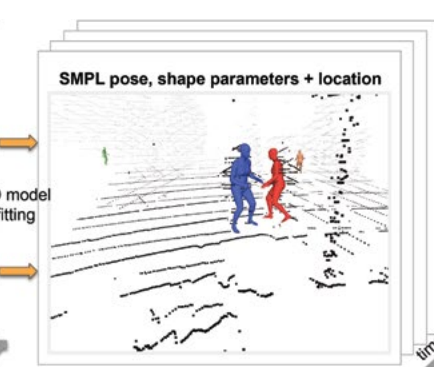
Related research that aims to loosen the constraints of human-annotated data was published in *Proceedings of International Conference on Robotics and Automation* (ICRA) 2017. In that work, Vasudevan and colleagues showed that synthetic data generated from videogame-like virtual simulations not only can quickly generate training data and annotations but that these simulations can train machine learning algorithms more effectively than human-annotated, real-world data.

The researchers, including Matthew Johnson-Roberson who codirects the FCAV with Vasudevan, have made the source code and data available to the research community.

"The only way we see these large, societal problems being resolvable is if we work on them as a community," Vasudevan said. "We want to be forward-thinking about how we create these tools so they can be most useful. That's in large part why this work has been moving forward at such a fast clip."







Our unique combination of processes will allow us to meet sub-100-nanometer resolution with a broad range of materials and enable the fabrication of new types of devices that can't be made with other processes.

High-resolution Platforms for Intelligent Manufacturing

and Novel Functional Devices

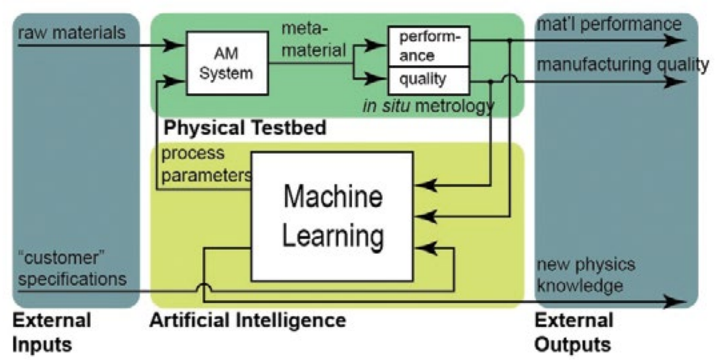
Understanding how materials interact with micro- and nanoscale manufacturing processes has been a long-standing and challenging problem for engineering researchers. And the way these interactions relate to the properties and behaviors of resulting functional devices is not well understood.

Now associate professor and Miller Faculty Scholar **Kira Barton** and colleagues are using tools and techniques from the fields of controls, robotics and artificial intelligence to create intelligent manufacturing frameworks and systems that can help provide answers.

SELF-DIRECTED SYSTEMS

Barton and colleagues, including professor **Max Shtein** from Materials Science and Engineering, as well as faculty from the Mechanical Engineering Department at The Ohio State University, have dubbed their framework MADE, or Manufacturing Autonomy for Directed Evolution. With MADE, the investigators are building machine learning mechanisms into manufacturing systems, giving these systems the capability to regulate themselves to attain desired properties and behaviors in the functional materials produced.

These functional materials are known as metamaterials, composites engineered with unique properties and capabilities, which can serve as entirely new devices for many purposes. The team is building an intelligent system while simultaneously exploring the connections among material compatibility and the manufacturing

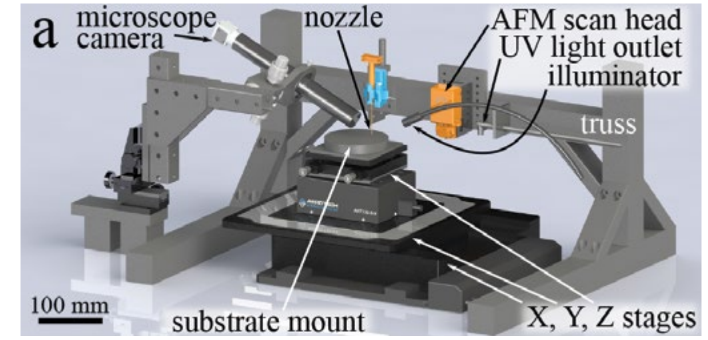


process to understand how best to leverage this new knowledge to achieve specific device capabilities.

"Robotics tools for monitoring, modeling and controlling systems help us look at how to use data and knowledge to direct learning about and the control of high-resolution additive manufacturing processes to achieve particular goals," Barton explained.

SCALABLE NANOMANUFACTURING FOR ADVANCED SENSORS

Armed with these types of robotics tools, Barton and other colleagues are developing a new nanomanufacturing platform. Working with collaborators including ME assistant professor **Neil Dasgupta**, and professors **Becky Peterson** and **Jay Guo** from Electrical Engineering and Computer Science, the platform combines two technologies: the electrohydrodynamic jet (e-jet) microscale additive manufacturing technique developed by Barton (and published in *Nature Materials* in 2007) and the spatial atomic layer deposition (ALD) technique developed by Dasgupta.



The researchers expect the resulting system to achieve the highest combination of resolution and throughput yet seen in additive manufacturing processes and possesses several distinguishing attributes, including high resolution—to less than 100 nanometers—and the ability to work with multiple, flexible and biologic materials. It also offers the ability to lay materials down on non-conventional, flexible and textured surfaces that exhibit out-of-plane features.

The fabricated device could measure eye pressure to **detect glaucoma or assess blood sugar** to monitor a patient with diabetes.

The system offers advantages over such processes as lithography, stamping and high-resolution dip-pen tracing, including non-contact manufacturing and a wider variety of usable materials.

"Our unique combination of processes will allow us to meet sub-100-nanometer resolution with a broad range of materials and enable the fabrication of new types of devices that can't be made with other processes," Barton said.

Currently, the team is working to build a combined platform to study the development of advanced sensors printed on contact lenses. The resulting non-invasive biomedical device could—continuously and invisibly to the wearer—measure eye pressure to detect glaucoma, for example, or assess blood sugar to monitor a patient with diabetes.

In fact, despite constraints, identifying materials with properties compatible with one another as well as with fabrication processes affords plenty of flexibility.

"You don't have to think in conventional ways," Barton said. "As an example, we can use e-jet as a positive mask to functionalize the material in certain locations and ALD to inhibit in other locations. We can also use e-jet to remove material—we now have so much more freedom in how we think about using and combining these processes given what we're learning about how materials interact."

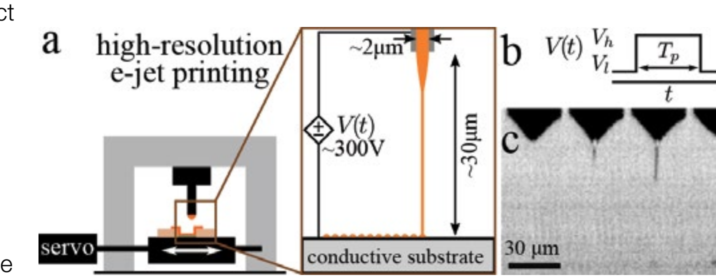
THE PATH TO COMMERCIALIZATION

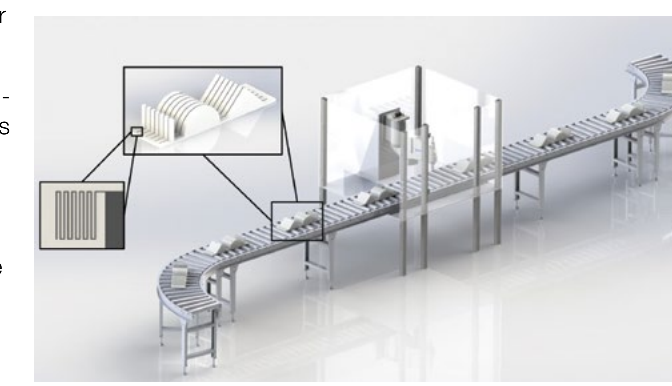
With two patents granted and several more filed, Barton and postdoctoral researcher **Leo Tse** are working to make the transition from research technology to commercially viable technology. Through a startup company, Specialty 3D (S3D) Print Heads, Barton plans to bring new products and capabilities—and a competitive advantage—to customers.

The group has been working with a number of organizations to push the technology toward commercialization, including the National Science Foundation Innovation Corps program, the Michigan Economic Development Corporation, the Michigan Translational Research and Commercialization Innovation Hub for Advanced Transportation and the U-M Office of Technology Transfer, as well as private investors.

Early applications of the devices' embedded electronic actuators, sensors, connectors and antennae are targeting the automotive sector to enable smart surfaces for autonomous vehicles. The U.S. Department of Defense, too, is interested in the translation of the technology for homeland security and military applications of similar smart surfaces.

"The abundance of materials to work with and the broad range of disciplines driving the motivations for making these devices bring great diversity in the backgrounds of students and collaborators and in applications," Barton said. "It's an incredibly exciting time to be working in this space."





TOP LEFT PAGE: PhD pre-candidate Nazanin Farjam works with Postdoctoral Researcher Leo Tse on the implementation of a novel integrated print head into a custom printing system. E-jet will be combined with the ALD process from Prof. Dasgupta's lab to provide unparalleled spatial resolution in three dimensions.

BOTTOM LEFT PAGE: Integrating Artificial Intelligence in additive manufacturing.

RIGHT PAGE, TOP, L-R CLOCKWISE: E-jet CAD image with integrated HR camera and AFM sensing. E-jet schematic with jetting behavior. High-throughput integrated precision printing system.

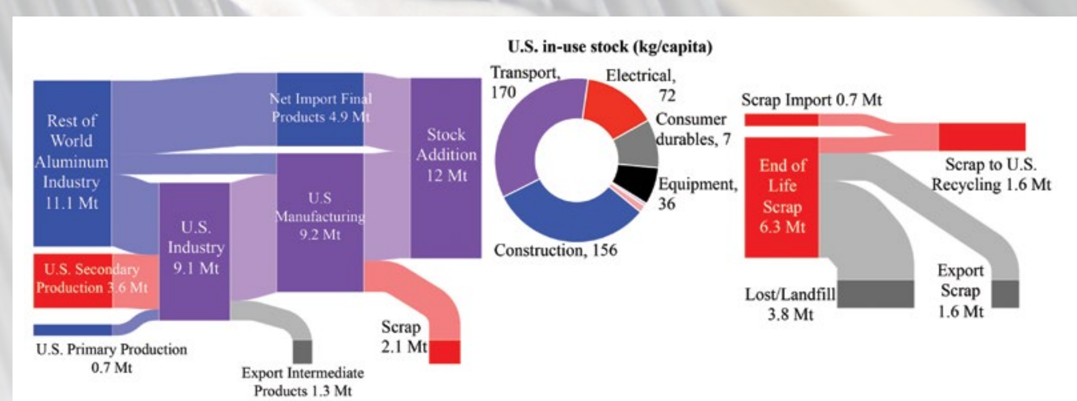
By optimizing extrusion parameters, Cooper's team have achieved strength and ductility comparable to conventional materials. When re-melted, the material achieves metal yields over 95 percent.

Improving Efficient Use of Materials: Resourceful Manufacturing and Design

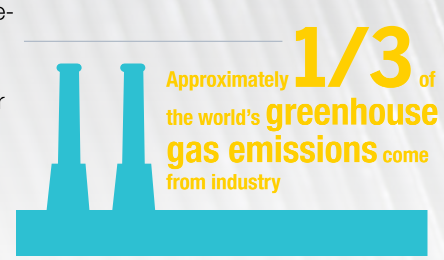
Approximately one-third of the world's greenhouse gas emissions come from industry, with over half of those emissions resulting from material production. Given thermodynamic limits, few options exist to dramatically improve the efficiency of material production, but how we use materials can have a large impact on total demand.

"We need to revisit how we design, manufacture and recycle the dominant metals of our age—steel and aluminum—which together account for 10 percent of global emissions," said Assistant Professor Dan Cooper, who leads the Resourceful Manufacturing and Design, or ReMaDe, laboratory at U-M. He also noted that emerging technologies and materials, such as additive manufacturing processes, will have an increasing impact in the near future, and that their sustainable adoption is paramount.

Cooper's research group focuses on the efficient use of materials in several ways: studying how materials flow through industry to produce final goods (to the right), how manufacturers can best adopt emerging technologies to make profits and reduce emissions, developing new metals processing technologies that reduce process scrap and make scrap easier to reuse and recycle and delving into the fundamental science underlying those options and technologies (background image).



In addition to the environmental benefits, large manufacturers are increasingly recognizing the financial gains from using materials more efficiently; for example, Cooper noted that Ford Motor Company is targeting $10 billion in material cost savings over the next five years.



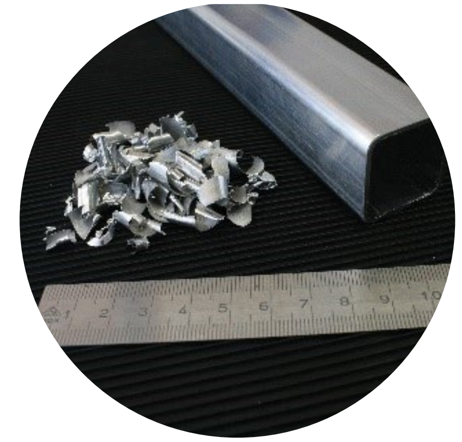
TOWARD MATERIAL CIRCULARITY FOR METALS

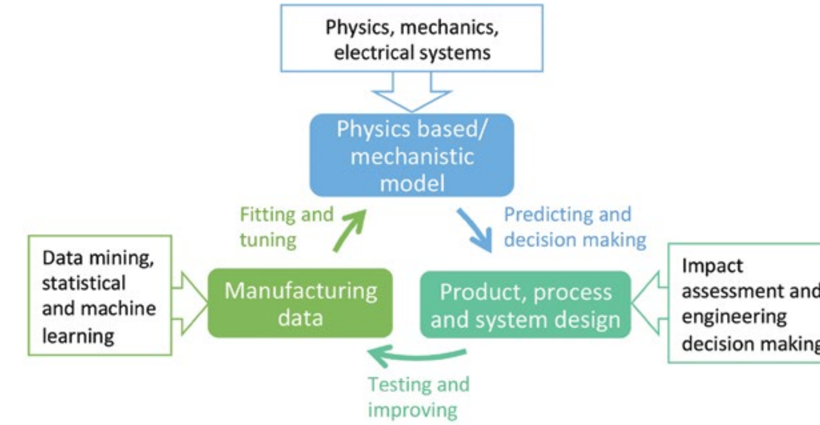
Per-capita demand for metal in the U.S. and many other high-income countries is saturating. "If we were able to recycle all end-of-life steel scrap in the U.S. domestically, we could displace all steel imports. This is good news in terms of decreased emissions—if we can effectively recycle the metal," he said.

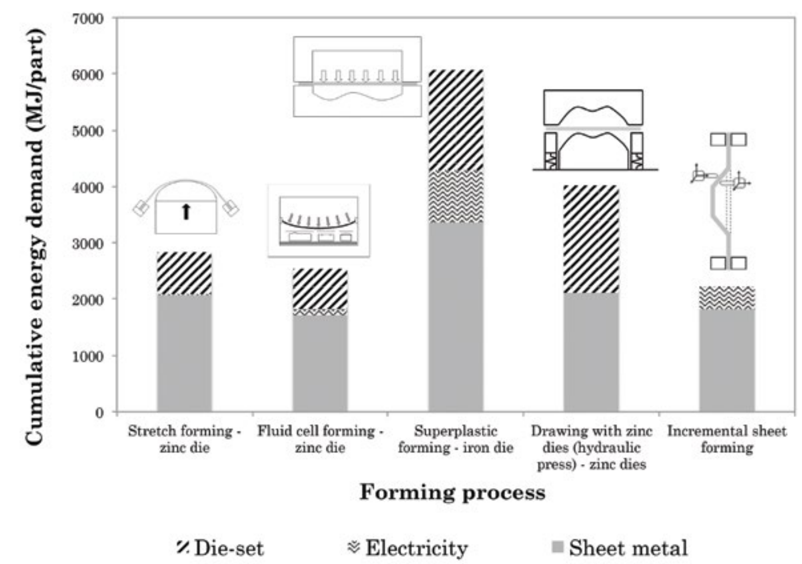
But material circularity has remained elusive since accumulated copper and tin content in steel, known as tramp elements, and silicon content (chief among other elements) in aluminum inhibit the production of wrought products, such as ductile sheet and wire. Contaminated scrap reduces the economic incentive to recycle, and scrap that is recycled requires either dilution with emissions-intensive new metal or down-cycling to lower-value products, such as cast aluminum engine blocks.

The problem will only be exacerbated by the shift toward electric vehicles, which can contain as much as double the copper content in their wiring and far fewer cast aluminum parts.

In a project with Ford and the Michigan-Cambridge Research Initiative, Cooper is mapping the changing material flow of steel and aluminum at both the alloy and application levels, allowing investigators to better understand which interventions, such as better design-for-recycling of products and end-of-life refining and separation technologies, can minimize dilution and down-cycling.







LOW-EMISSIONS TECHNOLOGIES FOR LIGHT METAL RECYCLING

In the drive toward weight reduction for improved fuel efficiency, manufacturers often produce optimized lightweight geometries by machining. In some cases, such as for aerospace components like a wing spar, up to 95 percent of the metal block is machined away, and the chips are difficult to recycle. Salt fluxes have often been used during re-melting to minimize melt loss, but the salts are expensive and the process can produce hazardous "salt cake."

Instead, Cooper's team is capitalizing on the way aluminum and magnesium readily weld together in the solid state to directly extrude usable components (inset figure). In addition, the team is producing a pre-melt compact that avoids the high metal losses associated with machining chips.

The group has experimented on aerospace-grade machining chips and, by optimizing extrusion parameters, has achieved strength and ductility of over 90 percent of conventional materials. When re-melted, the material achieves metal yields over 95 percent, equivalent to the melting of bulk metal (lower right).

Next steps are to validate the mechanistic models of chip welding under severe plastic deformation to optimize processes for a wider range of alloy systems. Cooper's group also is working to develop new machining technologies, such as new end-mill designs, that produce machining chips with enhanced recyclability while still providing a smooth surface finish on the machined workpiece.

ENVIRONMENTAL IMPACT MODELS FOR PROCESSES AND FACTORIES

The environmental impact models manufacturers can use to configure their processes and factories often are incomplete, inaccurate and quickly become outdated. This leaves manufacturers uncertain about how best to incorporate new technologies, such as additive manufacturing, into operations in the most cost- and energy-efficient way. Cooper is addressing this problem by developing data-reconciled mechanistic impact and cost models that leverage the large amounts of data manufacturers collect (top left).

Working with a local stamping supplier, Cooper is refining the models his team has developed (middle left). As with all of his work, "We want to provide information and develop processes that help manufacturers take concrete actions toward environmentally benign manufacturing," Cooper said.

BACKGROUND LEFT: Samples from a novel experiment designed to investigate aluminum solid-state welding.

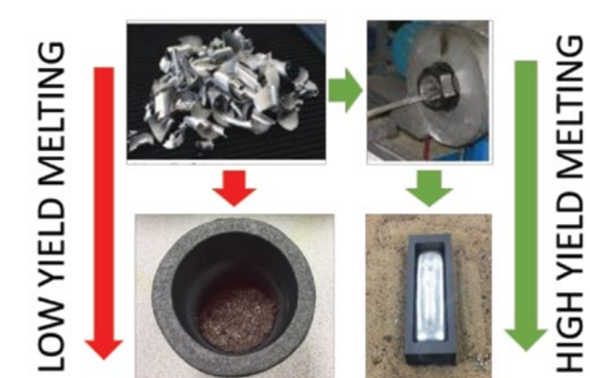
INSET LEFT: Annual aluminum flows in the United States. Preliminary work: Dan Cooper, Nicole Ryan, Kyle Syndergaard

TOP LEFT: A usable extrusion made directly from aerospace machining chips.

TOP RIGHT: Data-reconciled mechanistic impact and cost models to aid manufacturing decision-making. Preliminary work: Dan Cooper and Yongxian Zhu.

LEFT: Primary energy requirements for making 100 aluminum sheet metal part.

BOTTOM RIGHT: Dramatic reduction in melt losses during machining chip recycling.



ME Project-Based Design/Manufacturing Class Series
Thrives with Exciting Projects and DEI Initiatives

The ME Department's undergraduate curriculum has a unique team-based, Design-Build-Test spine of required classes. In Design and Manufacturing I, II and III (ME250, 350 and 450 respectively), sophomores, juniors and seniors turn concepts into real, working engineered systems and manufacturable products.

"In ME250, lecture material and hands-on experience introduce students to systems and design thinking as well as cascading objectives and requirements, a routine part of professional engineering projects in industry. The process is an in-depth one that requires all the students involved to go through a series of vigorous training modules, as ME Instructional Lab Manager **Toby Donajkowski** explains.

The modules are structured as to build a solid foundation in manufacturing and electronics. Once completed, the training allows ME students to utilize our state-of-the-art facilities including a manufacturing, mechatronics and assembly area," said Donajkowski. "To pull this off, there is an incredible amount of teamwork taking place throughout the ME faculty and support staff. Highly skilled technicians work directly with the students on a day-to-day basis throughout the semester. Behind the scenes are administrators, accountants, IT techs and a host of others who all play intricate roles in providing our students with the best service and experience possible."

A new student competition called "Game of Zones" was introduced for the 2017–2018 academic year. "In this project, the student teams design and build remote-controlled robotic devices, which cooperate to earn points in an obstacle course," said **Mike Umbriac**, ME lecturer and course instructor.

New obstacles for this game include a drawbridge that can be lowered, a seesaw that can be crossed, and pits of gravel that can be traversed. Another new addition to the ME250 course includes a DEI (Diversity, Equity & Inclusion) initiative, a mid-build survey that asks each student to reflect on the development of their own skills as well as their support for other team members in learning those skills.

In ME350, the emphasis is on modeling-based system design. Student teams design, build and test mechanisms to automatically catch falling balls and sort them by color. This academic year, ME350 is working toward adding more emphasis on manufacturing by illustrating the production processes used to make mechanical elements, electronic components and automotive batteries. The course is also adding a DEI activity into its lectures, focusing on different communication styles and conflict resolution.

The final course of the series, ME450, affords an opportunity for students to employ design processes to find solutions to real-world design challenges as part of a capstone design experience.

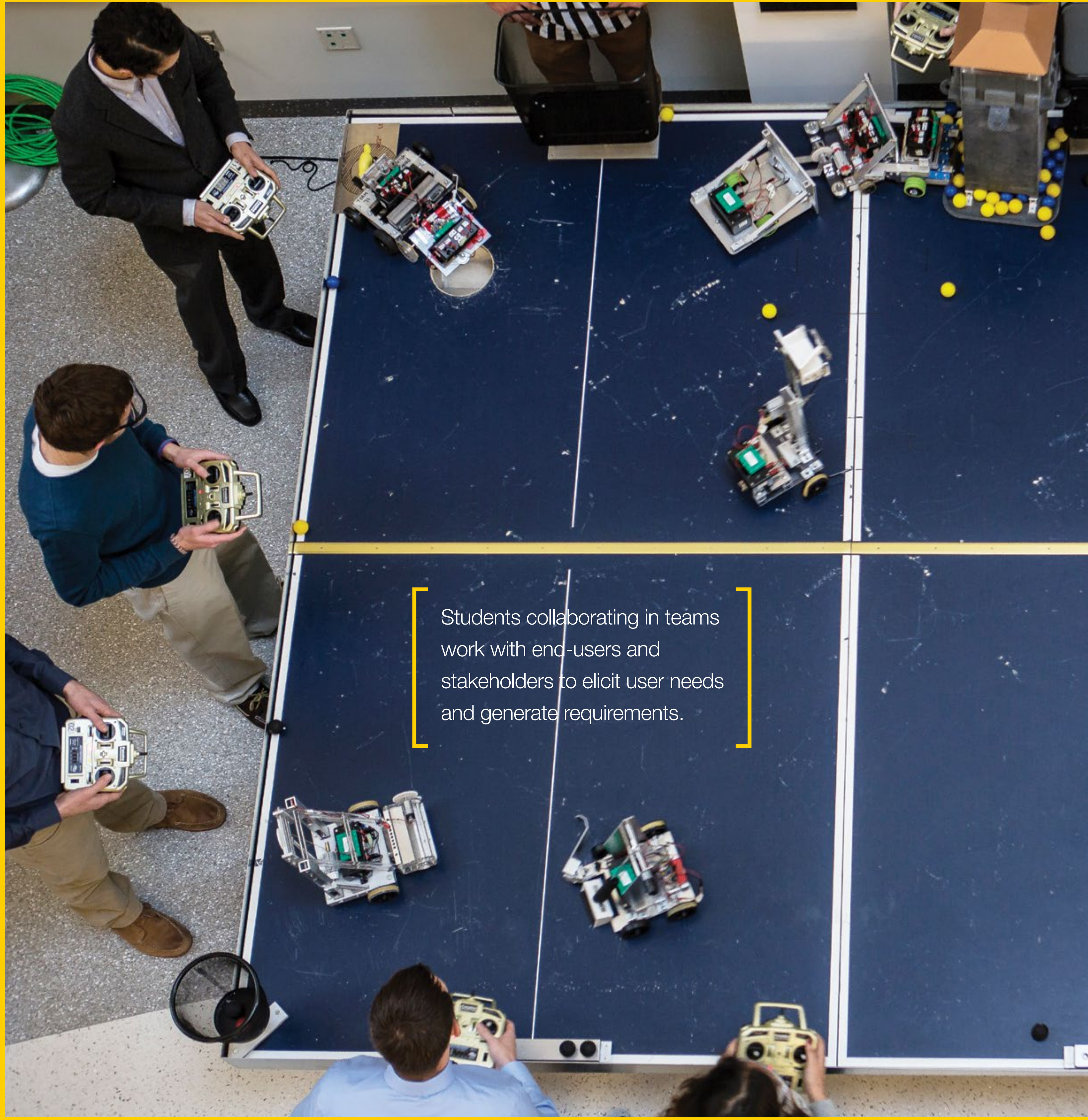
"Students collaborating in teams work with end users and stakeholders to elicit user needs and generate requirements," said ME lecturer and ME450 coordinator **Amy Hortop**. "They're able to develop and analyze concepts and validate their prototypes at a Design Expo held each April."

Each semester, various projects are proposed from industry to the U-M research community so that each team is working on a unique project.

"Thanks to our sponsors, we are very fortunate that we're able to offer a variety of projects every semester so that all students are working on a project that they are personally excited about," said Hortop.

According to Hortop, students are especially interested in projects that will make an impact on the community.

ME450 is always looking for capstone projects. If you have a project you'd like students to work on, or to learn more about the program, please contact Amy Hortop at abhortop@umich.edu or visit me450.engin.umich.edu.



[Students collaborating in teams work with end-users and stakeholders to elicit user needs and generate requirements.]

MEUS Continues to Grow

The sixth annual ME Undergraduate Symposia (MEUS) were held this past December and April, featuring 64 individual research projects that were presented along with more than 500 design team projects. The biannual 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 best poster, best paper and best session awards.

The next MEUS is scheduled for December 6, 2018. For more details about MEUS visit meus.engin.umich.edu. For more information on RISE, visit me.engin.umich.edu/academics/rise.

Poster image featured from November 2017 event

ME's Career Week Proving a Success

U-M ME continued our Career Week events this academic year. The event, which takes place in November and March, helps students in early career exploration determine whether their interests lie in academia or industry within the field of mechanical engineering. Career Week features events for both undergraduate and graduate students, including workshops geared toward successful resume building and talks with representatives from various industries such as automotive, energy and manufacturing. The Fall 2018 Career Week is scheduled for November 5–9, 2018.

Blazing Rays: U-M Solar Car Team's World Ranking Rises

After breaking out of a longtime, third-place rut, the U-M Solar Car Team's vehicle, Novum, took second place at both the 2017 World Solar Challenge (WSC) and the 2018 American Solar Challenge (ASC).

The second-place finish at the WSC in Australia was one of the team's proudest accomplishments of the past year, said **Chae Woo Lim**, a rising junior and the team's current engineering director and crew chief.

"Novum achieved an all-time best finish in the 2017 WSC. Not only was it the best finish for any U-M team; it was also the best finish for any American team in the competition since the inaugural competition," Lim said. The first WSC was held in 1987.

The stellar results were no small feat. Over 40 teams from around the world competed in the 3,000-kilometer competition, which stretches across the Australian outback from Darwin in the north to Adelaide in the south.

U-M Solar Car has been competing in the WSC since 1990, only a year after the team's founding. Since that time, the team has placed third in the competition five times—in 1990, 2001, 2005, 2009 and 2011.

"In 2017, we ended the curse," said **Clayton Dailey**, rising senior and team alumnus who served as engineering director and crew chief of the team that built Novum and raced Novum in the 2017 WSC. "2017 was a very special one for Michigan Solar Car."

Several factors contributed to the team's 2017 success. "We took the road less traveled and made Novum a monohull rather than catamaran design, which greatly decreased the amount of drag the car produced," Dailey said.

The vehicle is just one meter wide, one meter tall and five meters long and weighs in at approximately 400 pounds. And a triple junction gallium arsenide solar panel array confers about 34 percent efficiency, up from the 24 percent efficiency of the previous silicon array. The improvements give Novum a highway cruising speed of 55 mph.

The business team and sponsors contributed to the team's 2017—and 2018—success as well, including Platinum-level sponsors Eaton, Ford, General Motors, IMRA, Siemens and the U-M College of Engineering.

The renewed momentum led to the team also taking second place at the 2018 ASC, held in July. The more-than-1,500-mile race took competitors from Omaha, Nebraska, to Bend, Oregon. The U-M team's results were all the more notable given that it was composed of primarily incoming first-year students, now rising sophomores.

One significant obstacle the team faced was the need to get Novum into compliance with ASC rules, which differ from WSC rules. "Composite roll cages, for example, weren't allowed in the ASC, so the team had to design and create a metal roll cage that would sit right on top of the existing composite cage," Lim explained. "And then, because of the slight increase in width of the roll cage, we had to design and manufacture a brand-new canopy, canopy glass and array stand mechanism."

The hard work was worthwhile, and the team is looking toward the 2019 WSC.

"Our team's goal has traditionally been to win the World Solar Challenge," said Lim. "We're once again striving for that goal, and we got very close to achieving it last year. Now, we're aiming to fully design, manufacture and race a brand-new vehicle and bring the big trophy home."

Formula for a Winning 2018 Season

Each year, MRacing designs and builds a new race vehicle for the series' three competitions. The team's current vehicle, MR-18, is one of the lightest in its history , reduced 7 kg from last year's vehicle thanks to a focus on several mass reduction projects.

The team redesigned the chassis to extend the carbon fiber monocoque, used carbon fiber for the powertrain's fluid containers, designed a lightened engine crankshaft and used aluminum alloys for unconventional parts on the chassis, including the spindles and steering rack, according to **Michael Schickling**, a 2018 ME graduate and the team's technical director.

"We worked very hard to reduce mass, and the results paid off in our higher lateral capability," Schickling said.

Other improvements included a new Bosch Motorsport engine control unit with more advanced turbocharger, launch and traction control algorithms and new embedded microcontrollers for a driver dashboard, providing optimal shift points, engine configurations and other performance settings.

But a systemic misfiring engine issue hindered performance at the first competition of the season, held at Michigan International Speedway. The team finished 9th overall, including taking 7th place in autocross, 4th in skidpad and 4th in endurance.

After the race, the team worked tirelessly to resolve the problem. "We instrumented areas around our cylinder head and isolated the operating conditions that caused the misfiring. From there, we made changes to our heat shielding and engine calibration until the misfiring was eliminated," Schickling said.

The team's fixes were validated at the next competition, Formula North, in Ontario, Canada, where the team placed 2nd overall, including a 1st-place finish in acceleration, 2nd in skidpad and 2nd in endurance.

The team will next compete in August at Formula Student Spain. In preparation, MRacing participated, for the first time, in the Pittsburgh Shootout, a one-day Formula SAE autocross competition held at the Pittsburgh International Race Complex.

The event bodes well for Spain: MR-18 took 1st place.

Going forward after Formula Student Spain, the team will take some valuable lessons into the next season. A chassis manufacturing issue earlier this season brought the team together to reorganize its manufacturing timeline to ensure it would meet its on-track targets.

The manufacturing issues had little to no impact on competition results, said Schickling, who will return to ME in the fall to pursue a master's degree and will advise the MRacing team. But, he added, the experience underscored "that communication and organization are critical since time is such a limited resource for the team. There are a few team members who are willing to commit 40 to 60+ hours a week, but that time can be wasted without effective organization."

Michigan Baja: Off-Road Rocks

Michigan Baja Racing finished the 2018 competition season in third place overall and brought home its sixth consecutive—and eighth overall—Mike Schmidt Memorial Iron Team Award.

Each year, the team designs a single-seat, off-road vehicle to compete in the SAE Baja collegiate design series. This year's vehicle, the team's 29th, featured a completely redesigned brake system using one-piece sliding calipers and a custom master cylinder that the team machined in-house.

"We significantly reduced the complexity of the system to achieve more reliable braking," said incoming Team Captain **Erica Tevere**, a rising senior.

Other changes included redesign of suspension kinematics to increase rear shock travel, a redesigned frame to increase torsional stiffness and reduce weight, a greater focus on vehicle aerodynamics to increase top speed and custom carbon fiber tie rods. Many of the changes were aimed at reducing component weight while maximizing component strength in application, contributing to improved vehicle performance overall.

Tevere oversaw much of the experimentation, testing and validation of the tie rods' carbon-aluminum bonding. "We saw no signs of failure after the three competitions," she said.

At the first competition in Maryland, Michigan Baja took second place overall, earning just one point less than the first-place finisher. The U-M team took first in the endurance event, "our biggest accomplishment of the Maryland competition," Tevere said.

At the second competition in Kansas, Michigan Baja came in seventh overall in spite of heavy rains and a hailstorm that shut down the course for several hours, making conditions even more challenging than usual.

With only a week back in Ann Arbor before heading to Oregon for the third and final competition of the season, Tevere said, "we were crossing our fingers that nothing major would need to be fixed."

Fortunately nothing did, but during the endurance race of the Oregon competition, the car had to come off the track multiple times due to a failed rear hub and issues with the custom continuously variable transmission.

"It's easy to lose motivation when a part you engineered breaks, but how the team handled the failures were impressive," Tevere said. "It was a tight race, and spending as little time as possible in the paddock helped us finish third in the competition and third for the season. We were able to stay focused and get the car back on the track quickly."

To prepare for quick fixes, the team makes spares of all parts: "one on the car and at least one spare off," Tevere said. "We love to do as well as we can at competition, and a lot of that is building a great car, but the team also has to be ready in case of catastrophic failures when it comes off the course."

Doing well at competition is, once again, the team's goal for the upcoming season. "We want to keep the legacy going, and we'd love to get a First Place Mike Schmidt Memorial Iron Team Award finish – that's our goal every year, and we know we can do it," said Tevere.

Leading Michigan Baja is exciting, she added. "It can be challenging to lead so many people with such a diverse range of opinions, but I think we have a really good, capable team to get the results we want this year."

Vozar Honored with 2018 Michigan Engineering Outstanding Recent Alumni Award

Mechanical Engineering alumna Katherine Avery Vozar has been selected to receive the 2018 University of Michigan Engineering Outstanding Recent Alumni Award. Vozar (MSE 11', PhD, 16') is currently a Technology Integration Lead at Ford Motor Company, where her work is dedicated to integrating emerging technology into forward model year vehicles, and accelerating systems-based, cross-functional development and implementation of relevant technologies sourced from multiple industries. Vozar also brought her unique vision and experience to assist as a Corporate Partner-in-Residence at Techstars Mobility, a Detroit-based startup accelerator focused on funding companies with a novel approach to transportation, including (but not limited to) autonomous, connected, shared and electric vehicles.

Vozar has written more than 20 peer-reviewed articles and holds multiple patents, has co-advised doctoral students with faculty from around the world and has provided technical and project leadership on multiple government-funded multi-institution research collaborations. Giving back to her community is another passion of Vozar's. As a student at U-M ME, she led multiple student groups and initiated a STEM outreach program in Ypsilanti, MI that served more than 200 elementary school students each year. As an alum, she became a member of the Michigan Engineering Alumni Board and a founding member of the Advisory Board for the Michigan Engineering Zone in Detroit. Her vision for education as the vehicle for social equality recently led her to start a nonprofit organization, The Trending Up Foundation, which endeavors to raise awareness and accessibility of STEM careers for grade-school students from historically excluded groups through hands-on workshops, classes and scholarship opportunities.

Hammonds Honored with 2018 U-M ME Alumni Merit Award

Mechanical Engineering alumna **Kimberly Hammonds** has been selected to receive the 2018 University of Michigan (U-M) Mechanical Engineering (ME) Alumni Merit Award. Hammonds (BSME, '90) most recently served as the Group Chief Operating Officer of Deutsche Bank, where she was the third female in its history to serve on the Management Board of the 148-year-old company. She was named one of the top 10 Digital Leaders in Germany. Throughout her career Hammonds has worked in four different industries; automotive, technology, aerospace and defense, and, most recently, financial services. She served as the Group Chief Information Officer for the Boeing Company, and was the first female CIO in the company's history. She also held executive positions at Dell Corporation and Ford Motor Company. Her global leadership experience extends across product engineering, manufacturing, supply chain, marketing, purchasing, operations and information technology.

Hammonds is a member of the Society of Women Engineers, serves on the Board of Directors of Redhat, Cloudera and Tenable, and is the founder and president of The Zoe Foundation, which provides art programs for cancer patients. She has actively supported the American Cancer Society, raising more than $5 million for the organization. She was recognized by *Crain's Business* as one of the 'Women to Watch' in 2011.

Korybalski Lecture Brings C.D. Mote, Jr. to Campus

Pictured from left, Kon-Well Wang, C.D. Mote, Jr. and Michael Korybalski

C.D. Mote, Jr., President of the National Academy of Engineering, delivered the University of Michigan Mechanical Engineering 150th Anniversary Michael Korybalski Distinguished Lecture on May 18, 2018. Mote's talk, which was titled "The Grand Challenges Scholars Program: Preparing Students for Global Engineering," focused on the challenges facing the engineering profession in the global environment of the 21st century.

Mote is the president of the National Academy of Engineering. He held an endowed chair in mechanical systems at Berkeley, chaired the Mechanical Engineering Department from 1987 to 1991 and served as vice chancellor from 1991 to 1998. In 1998, Mote was named president of the University of Maryland, College Park, a position he held for 12 years when he was appointed Regent's Professor.

As president of the NAE, Mote's goal is to ensure highly competitive talent for the 21st-century engineering workforce, to facilitate public understanding of engineering by demonstrating how engineering creates a better quality of life and serves society and to engage the academy in global engineering issues in support of national interests.

Mote's lecture was a part of the annual lectureship endowed by Michael Korybalski, chair of the ME External Advisory Board and former chief executive officer of Mechanical Dynamics. The lectureship was created as a means to bring high-profile, inspiring speakers to the U-M community to help promote the impact of engineers on large societal problems.

Faculty Awards & Recognition

EXTERNAL AWARDS

ELLEN ARRUDA
National Academy of Engineering, 2017
Society of Engineering Science (SES) James R. Rice Medal, 2018

ARVIND ATREYA
SFPE Arthur B. Guise Medal, 2017

SHORYA AWTAR
ASME Fellow, 2017
ASME Best Paper on Mechatronics Award, 2017

JIM BARBER
ASME Mayo D. Hersey Award (Tribology Division), 2017

KIRA BARTON
ASME DSCD Outstanding Young Investigator Award: Dynamic Systems and Controls Division, 2017

DIANN BREI
ASME Adaptive Structures and Material Systems Award, 2018

NEIL DASGUPTA
3M Non-Tenured Faculty Award, 2017
SME Yoram Koren Outstanding Young Manufacturing Award, 2017
DARPA Young Faculty Award, 2018
NSF CAREER Award, 2018

YUE FAN
ASME Haythornthwaite Young Investigator Award, 2017

JACK HU
SME Gold Medal, 2017
Foreign Member of the Chinese Academy of Engineering, 2018

NOBORU KIKUCHI
National Academy of Engineering, 2017

YORAM KOREN
SME Yoram Koren Outstanding Young Manufacturing Engineer Award (Namesake), 2017
IJPR (International Journal of Production Research) Best Paper Award, 2018

JYOTI MAZUMDER
ASME M. Eugene Merchant Manufacturing Medal, 2017
TMS Bruce Chalmers Award, 2018

CHINEDUM OKWUDIRE
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

KAZU SAITOU
IEEE Fellow, 2017

ALBERT SHIH
SME Frederick Taylor Research Medal, 2018

VOLKER SICK
Fellow of the Combustion Institute, 2018

JASON SIEGEL
IEEE Control Systems Technology Award, 2017

KATHLEEN SIENKO
ASME Engineering Education Donald N. Zwiep Innovation in Education Award, 2018

ALBERT SHIH
SME Frederick Taylor Research Medal, 2018

ANNA STEFANOPOULOU
IEEE Control Systems Technology Award, 2017
SAE Fellow, 2018

TRAVIS THOMPSON
Forbes' "30 Under30" for Energy (Forbes Magazine's top energy tech entrepreneurs under the age of 30), 2017

GALIP ULSOY
ASME Rudolf Kalman Best Paper Award, 2017

RAM VASUDEVAN
Office of Naval Research (ONR) Young Investigator Award, 2018
NSF CAREER Award, 2018

ANGELA VIOLI
Adel Sarofim Award, 2017

KON-WELL WANG
ASME J.P. Den Hartog Award, 2017
Pi Tau Sigma-ASME Charles Russ Richards Memorial Award, 2018

U-M AWARDS

ELLEN ARRUDA
Maria Comninou Collegiate Professor of Mechanical Engineering, 2017

SHORYA AWTAR
CoE Rexford E. Hall Innovation Excellence Award, 2017

MIKI BANU
CoE Kenneth M. Reese Outstanding Research Scientist Award, 2017

KIRA BARTON
Miller Faculty Scholar, 2017

ANDRÉ BOEHMAN
ME Department Achievement Award, 2018

DIANN BREI
CoE Monroe-Brown Foundation Service Excellence Award, 2017
Rackham Master's Mentoring Award, 2017

NEIL DASGUPTA
ME Department Achievement Award, 2018

BOGDAN EPUREANU
CoE Faculty Recognition Award, 2017

JIANPING FU
CoE George J. Huebner, Jr. Research Excellence Award, 2018

JOHN HOARD
CoE Kenneth M. Reese Outstanding Research Scientist Award, 2018

ERIC JOHNSEN
ME Department Achievement Award, 2017

SRIDHAR KOTA
Distinguished University Innovator Award, 2017

GRANT KRUGER
Research Faculty Recognition Award, 2018

WEI LU
CoE Ted Kennedy Family Team Excellence Award, 2017

CHINEDUM OKWUDIRE
ME Department Achievement Award, 2017
MLK Spirit Award, 2017

HUEI PENG
E. & M. Ulsoy Citation Leader Award, 2018

C. DAVID REMY
CoE Jon R. and Beverly S. Holt for Excellence in Teaching Award, 2018

VOLKER SICK
President's Award for Distinguished Service in International Education, 2018

ANNA STEFANOPOULOU
William Clay Ford Collegiate Professor of Manufacturing, 2017
CoE Vulcans Education Excellence Award, 2018
Rackham Distinguished Graduate Mentor Award, 2018

MICHAEL THOULESS
CoE Ted Kennedy Family Team Excellence Award, 2017

MARGARET WOOLDRIDGE
CoE Neil Van Eenam Memorial Undergrad Teaching Award, 2017

Student Awards

GRADUATE STUDENT AWARDS

CESAR BARRAZA-BOTET
Christine Mirzayan Science and Technology Policy Graduate Fellow 2018

DANIEL BRUDER
National Science Foundation Graduate Research Fellowship Program 2017

ANDREW DAVIS
National Science Foundation Graduate Research Fellowship Program 2017

MENG TING CHUNG
Outstanding Student Paper Award, International Conference on Micro Electro Mechanical Systems (MEMS) 2018

LONGJI CUI
ASME Megatronics Award 2017
Rackham PreDoctoral Fellowship 2018
Richard F. And Eleanor A. Towner Prize 2018

SAM DALY/JOHN SHAW
Robert M. Caddell Memorial Team Award for Research 2018

SHANNON DANFORTH
National Science Foundation Graduate Research Fellowship Program 2018

ANDREW DAVIS
National Science Foundation Graduate Research Fellowship Program 2017

ANDREW EDOIMIOYA
National Science Foundation Graduate Research Fellowship Program 2018

ANDREW GAYLE
National Science Foundation Graduate Research Fellowship Program 2018

HAOWEN GE
William Mirsky Memorial Fellowship 2017
CoE Distinguished Achievement Award 2017

AMIN GHADAMI
Rackham PreDoctoral Fellowship 2018

MEGAN HATHCOCK
National Science Foundation Graduate Research Fellowship Program 2017

CHAOZHE HE
Richard F. and Eleanor A. Towner Prize For Outstanding Graduate Student Instructors 2018

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

KENNETH HO
McIvor Memorial Award 2017

SAEED KAZEMIABNAVI
Towner Prize for Distinguished Academic Achievement 2017

NARAYANAN KIDAMBI
Richard F. and Eleanor A. Towner Prize For Distinguished Academic Achievement 2018

JIN WOO LEE
Richard F. and Eleanor A. Towner Prize For Outstanding Graduate Student Instructors 2018

WILL LEPAGE
Robert M. Caddell Memorial Team Award for Research 2018

CALLAN LUETKEMEYER
J. Robert Beyster Computational Innovation Graduate Fellows Program 2018

SHIHAN LU
William Mirsky Memorial Fellowship 2018

BRYAN MALDONADO
Tau Beta Pi Michigan Gamma Scholarship 2018

EVA MUNGAI
National Science Foundation Graduate Research Fellowship Program 2017

JOSHUA NKONGE
National Science Foundation Graduate Research Fellowship Program 2018

MICHAEL POTTER
National Science Foundation Graduate Research Fellowship Program 2018

BHUPENDERA PRASHANTH
William Mirsky Memorial Fellowship 2018

AGNES RESTO
National Science Foundation Graduate Research Fellowship Program 2017

VICTOR RODRIGUEZ
National Science Foundation Graduate Research Fellowship Program 2018

RYAN ROSARIO
National Science Foundation Graduate Research Fellowship Program 2017

ADRIAN SANCHEZ
National Science Foundation Graduate Research Fellowship Program 2017

ARITRA SASMAL
Alexander Azarkhin Scholarship 2017

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

GREG SHALLCROSS
NASA Space Technology Research Fellowship 2017
National Science Foundation Graduate Research Fellowship Program 201

YUE SHAO
ProQuest Distinguished Award 2017
Towner Prize for Outstanding PhD Research 2017

ISAAC SPIEGEL
Richard F. and Eleanor A. Towner Prize For Outstanding Graduate Student Instructors 2018

SHIN-JANG SUNG
McIvor Memorial Award 2016
SAE Henry O. Fuchs Student Award 2017

MICHAEL WADAS
Department of Energy National Nuclear Security Administration Stewardship Science Graduate Fellowship 2018

BIN WU
Alexander Azarkhin Scholarship 2018
McIvor Memorial Award 2018

SHENGJIA WU
William Mirsky Memorial Fellowship 2017

YEVGENIY YESILEVSKIY
Richard F. and Eleanor A. Towner Prize For Outstanding Graduate Student Instructors 2018

UNDERGRADUATE STUDENT AWARDS

ROY BERG
College of Engineering Distinguished Leadership Award 2018

LAINE CHAN
College of Engineering MLK Spirit Award 2018

YUNSEOK CHOI
RISE Best Paper Fall 2017

JAMES CORCORAN
R&B Machine Machine Tool Company Scholarship 2018

MICHAEL DALY
R&B Machine Machine Tool Company Scholarship 2018

MICHAEL FISHER
J.A. Bursley Mechanical Engineering Award 2018

CHLOE HENDERSON
ME Spirit Award 2018

JASON KERTAYASA
R&B Machine Machine Tool Company Scholarship 2018

DANIEL KNISTER
Tom S. Rice Tau Beta Pi Award 2018

VLADIMIR KROKHMAL
Lloyd H. Donnell Scholarship Fund 2018

BENNET MCGLADE
Robert M. Caddell Memorial Scholarship 2018

ELIJAH PARHAM
R&B Machine Machine Tool Company Scholarship 2018

SAMUEL PARHAM
R&B Machine Machine Tool Company Scholarship 2018

YATRI PATEL
College of Engineering Distinguished Achievement Award 2018

GRACE STRIDICK
College of Engineering Distinguished Leadership Award 2018
Charles F. Barth, Jr. Prize 2018

MATTHEW WALDMANN
Robert M. Caddell Memorial Scholarship 2018

JOHN WEEKS
Robert M. Caddell Memorial Scholarship 2018

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INSIDE BACK COVER: The Ann & Robert H. Lurie Bell Tower, located on U-M's North Campus, shows up in a reflection of GG Brown's light wall at sunrise.

Photo: Michigan Photography

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