College of Engineering
UNIVERSITY OF WISCONSIN–MADISON

FALL 2024 NEWSLETTER

DEPARTMENT OF
MECHANICAL ENGINEERING

Greetings! I am delighted to share the latest updates from the department, showcasing how your continued support is fueling our growth and innovation in both education and research.

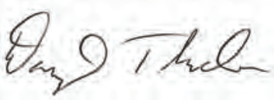
There are more than 1,400 students pursuing undergraduate ME or engineering mechanics degrees at UW-Madison, representing nearly a 25% increase over the past five years. To accommodate this growth, we remodeled multiple instructional labs over the summer. A highlight is a new mechatronics lab, which all ME students now take to learn about embedded systems that couple microcontrollers, actuators and sensors—essential skills for today's engineers. We also opened a new lab dedicated to experimental vibrations and controls. Finally, we doubled the capacity of our measurements lab and improved the layout and functionality of our intro lab, a critical space for fostering community among our freshmen students. These enhancements will ensure our students gain in-depth, practical experience with industry-relevant technologies.

Our strategic faculty hiring efforts over the past three years have been a catalyst for groundbreaking research in artificial intelligence/machine learning, energy storage, robotics, aerospace engineering, mechanics and manufacturing. We have four new faculty starting this academic year: Xiao Kuang, who specializes in polymers and additive manufacturing, with applications in biomedical systems; Weiyu Li, who performs computational modeling of batteries and energy systems; Prateek Jaiswal, who specializes in experimental aerodynamics and aeroacoustics; and Thomas Breunung, who is an expert in structural dynamics with applications in aerospace and energy harvesting. Our hiring efforts will continue in 2024-25 with six additional faculty openings in robotics, high-speed flows, mechanics of battery materials, net zero off-road mobility, autonomous experimentation and digital twins. The future is bright with an influx of talented young faculty addressing major technological challenges.

Over the summer, we bid fond farewells to longtime faculty members Tim Osswald and Wendy Crone, both of whom had incredible careers and will be deeply missed. Tim was a popular instructor, the founding co-director of the Polymer Engineering Center, the advisor of the Society of Hispanic Professional Engineers, and a valued colleague with a keen sense of history. Wendy was an exceptional researcher and instructor in mechanics, held numerous college and campus leadership roles, and was a highly sought-after mentor to students, staff and faculty. We thank Tim and Wendy for their many contributions and wish them the best as they transition to other pursuits.

Thank you for your unwavering interest and dedication to the department. Your passion propels us forward and shapes the future of mechanical engineering and engineering mechanics at UW-Madison.

On, Wisconsin!



Darryl Thelen
John Bollinger Chair of Mechanical Engineering
& Bernard A. and Frances M. Weideman Professor
(608) 262-1902
dgthelen@wisc.edu

Historic gift for new engineering building

A $75 million gift will fuel construction of a much-needed new building for the College of Engineering.

With their lead gift—the largest single gift in college history—brothers and UW-Madison L&S alumni Marvin and Jeffrey Levy are honoring the memory of their brother, Phil, who passed away in 2021. Phil earned an English degree from the university in 1964; the Levy family has a long history of involvement in and support for UW-Madison.

A stunning facility that marries intentional design with future-ready engineering flexibility, the Phillip A. Levy Engineering Center will be the new centerpiece of the College of Engineering campus. The transformative facility will inspire future engineering leaders, spark collaboration and yield breakthroughs that echo across generations. Enabling work for the building already has begun.

engineering.wisc.edu/me
linkedin.com/school/UWMechEngr
@UWMechEngr
@UWMechEngr

On the cover: PhD student Katherine Heidi Fehr and Associate Professor Peter Adamczyk conduct a 3D scan of a shoe, with a motion sensor attached on top, as part of their new method for studying gait. Photo: Tom Ziemer.

The researchers' sensors can monitor nitrate leaching and help guide best practices for mitigating its harmful effects. Soil science PhD student Shuohao Cai installs a sensing rod to test the team's technology. Photo: Kuan-Yu Chen.

Printed sensors in soil could help farmers improve crop yields and save money

UW-Madison engineers have developed low-cost sensors that allow for real-time, continuous monitoring of nitrate in soil types that are common in Wisconsin. These printed electrochemical sensors could enable farmers to make better informed nutrient management decisions and reap economic benefits.

"Our sensors could give farmers a greater understanding of the nutrient profile of their soil and how much nitrate is available for the plants, helping them to make more precise decisions on how much fertilizer they really need," says Assistant Professor Joseph Andrews, who led the research. "If they can buy less fertilizer, the cost savings could be quite significant at large-acreage farms."

While nitrate is an essential nutrient for growing crops, excess nitrate can leach out of soil and into groundwater. This type of pollution is dangerous for people who drink contaminated well water and is harmful for the environment. The researchers' new sensors could also be used as an agricultural research tool to monitor nitrate leaching and help guide best practices for mitigating its harmful effects.

Current methods for monitoring nitrate in the soil are laborious, expensive and don't provide real-time data. That's why Andrews, an expert in printed electronics, and his team set out to create a better and less costly solution.

For this project, the researchers used an inkjet printing process to fabricate potentiometric sensors, a type of thin-film electrochemical sensor. Potentiometric sensors are commonly used to accurately measure nitrate in liquid solutions. However, these sensors aren't typically suitable for use in soil environments, where coarse soil particles will scratch them and interfere with obtaining accurate measurements.

"The main challenge we were trying to solve is figuring out a way to enable these electrochemical sensors to work well in the harsh environment of soil and accurately sense nitrate ions," Andrews says.

The team's multifunctional "stickers" have sensors for measuring nitrate, moisture and temperature. Photo: Joel Hallberg.

The team's solution was to place a layer over the sensor made from polyvinylidene fluoride. Andrews says this material has two key features. First, it has very tiny pores, about 400 nanometers in size, that allow nitrate ions to pass through while blocking soil particles. Second, it's hydrophilic, meaning it attracts water and acts like a sponge to absorb it.

The team has tested its sensors in two different soil types that are relevant for Wisconsin—sandy soil, which is common in the north-central part of the state, and silt loam soil, which is common in southwestern Wisconsin—and found that the sensors produced accurate results.

The researchers are incorporating their nitrate sensors into a multifunctional sensing system they call a "sensing sticker," in which three different kinds of sensors are mounted on a flexible plastic surface with an adhesive on the back. These stickers also contain moisture and temperature sensors.

The researchers attach several sensing stickers to a rod, positioning them at different heights, and then bury the rod in the soil. This setup allows them to take measurements at multiple depths in the soil.

"By measuring the nitrate, moisture and temperature at different depths, we can now quantify the process of nitrate leaching and capture how nitrate is moving through the soil, which hasn't been possible before," Andrews says.

The researchers are patenting their technology through the Wisconsin Alumni Research Foundation.

FOCUS ON NEW FACULTY

Xiao Kuang aims to 3D print into deep regions to enhance sustainability and improve health

A doctor repairs a patient's knee cartilage and bone using a 3D-printing process, driven by ultrasound, that occurs inside the patient's body. And the procedure is minimally invasive. Xiao Kuang is developing soft (bio)materials and advanced manufacturing technologies that could enable such medical procedures in the future.

Situated at the intersection of materials, manufacturing and medicine, Kuang's research extends to broad applications—including aerospace, soft robots, biomedical devices, drug delivery and tissue engineering—to solve societal challenges in sustainability and health. Kuang, who joined the department as an assistant professor in August 2024, also will play a key role in the Polymer Engineering Center.

Using experiments, theoretical analysis and computational tools, Kuang studies how polymeric systems respond to stimuli such as heat, light, chemical, mechanical and acoustic fields. "I'm particularly interested in understanding how external stimuli interact with polymers at the molecular level and also at larger scales," he says. "This interaction can trigger physical and chemical responses that could cause material construction/destruction, shape-changing, self-healing or growth."

At UW-Madison, Kuang plans to especially focus on ultrasound as an external stimulus. That's an area in which he is already a pioneer. Because ultrasound waves can penetrate into deep regions, such as thick biological tissues, Kuang created an innovative ultrasound printing technique called deep-penetration acoustic volumetric printing—and that enables 3D printing inside the body.

The technique involves a special kind of polymer ink that can be injected into the body; the ink responds to ultrasound by transforming from liquid to solid. Kuang and his collaborators also developed an ultrasound 3D printer using a focused ultrasound transducer so they could precisely focus the ultrasound waves. By combining these two technologies, Kuang focused the ultrasound energy to quickly solidify the polymer ink and build a custom structure inside of materials that scatter light—including under centimeters-thick tissue.

Kuang earned his PhD in polymer chemistry and physics from the University of Chinese Academy of Sciences in 2016. He worked as a postdoctoral researcher at Georgia Institute of Technology and Brigham and Women's Hospital & Harvard Medical School before joining UW-Madison.

FOCUS ON NEW FACULTY

Weiyu Li uses computational modeling to enhance energy sustainability

To enable electric vehicles with greater range and electrified aviation, we need batteries with increased energy density that are safer and can last longer.

Weiyu Li is leveraging her expertise in theoretical and computational modeling of electrochemical transport in energy systems to address this challenge. In her research, she develops efficient mathematical models and numerical algorithms that enhance sustainable energy conversion, utilization and decarbonization.

"With these multiscale models of electrochemical transport, I want to create a battery avatar that combines physics-based models and various data streams," Li says. "This will yield improved predictions of physico-chemical processes inside battery systems and help guide materials design for the next generation of high-energy-density batteries with enhanced safety and longevity."

Li joined the department as the Alfred Fritz Assistant Professor in fall 2024. She earned her master's degree in mechanical and aerospace engineering from Princeton University, and in 2023 she received her PhD in energy science and engineering from Stanford University.

Li is driven by curiosity, which led her to contribute to multiple interdisciplinary research projects early in her PhD before deciding to focus on energy system modeling for her dissertation.

"I was lucky that my PhD advisor was very flexible and open-minded, and he encouraged me to explore different areas," she says. "So, I worked on a data simulation and smart agriculture project as well as biomedical modeling projects investigating blood transfusion and an approach for treating acute respiratory distress syndrome. I will continue working in these different areas in addition to my main focus on energy system modeling, as they are all related to sustainability."

Prior to joining UW-Madison, Li was a postdoctoral scholar in the departments of physics and materials science and engineering at Stanford University.

FOCUS ON NEW FACULTY

Prateek Jaiswal is harnessing fluid mechanics for sustainable transportation and energy systems

While pursuing his master's degree in aerospace mechanics and avionics at ISAE-SUPAERO in Toulouse, France, Prateek Jaiswal encountered aeroacoustics, a field in which researchers study noise generation via either turbulent fluid motion or aerodynamic forces interacting with surfaces.

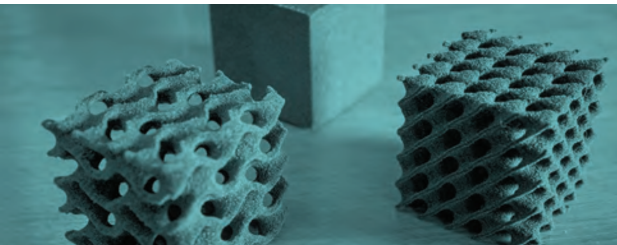
"I became very interested in aeroacoustics because I saw immense opportunities in this field," says Jaiswal, who joined the department as an assistant professor in fall 2024. "For example, new types of aircraft such as drones, air taxis and vertical flying aircraft are being developed and they will operate much closer to where people live. So finding ways to reduce their noise is crucial for the sustainable development of these transportation systems as well as energy systems like wind turbines that create a lot of noise."

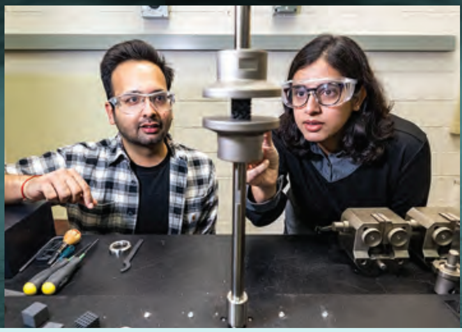
Beyond being an annoyance to people nearby, the noise pollution from these technologies could also have implications for human health. Jaiswal points to a 2015 study in the journal *BMC Public Health* that found noise exposure is associated with high blood pressure.

An expert in experimental fluid mechanics, Jaiswal focuses on understanding how the structure of turbulent shear flows dictates drag, noise and their propagation. This knowledge could enable new machines that are quieter and have lower resistance when traveling through unsteady flow.

"In transportation, a large fraction of energy is spent overcoming this resistance to the flow, so by finding ways to reduce drag I aim to help reduce the carbon footprint," he says. Jaiswal also seeks to improve the reliability of structures by better understanding flow-induced vibration.

Jaiswal earned his PhD in mechanical engineering from the Université de Sherbrooke in Quebec, Canada, in 2020. Prior to joining UW-Madison, he was a Marie Curie postdoctoral fellow at the University of Southampton in the United Kingdom.





Associate Professor Pavana Prabhakar, right, and PhD student Hridyesh Tewani create the foams using 3D printing, which allows them to customize the material for many different uses. Photo: Joel Hallberg.

New 'structures within structures' foam softens a blow and bounces right back

It might put an extra bounce in your step or add resilience to the hull of a ship: The unique internal structure of a lightweight 3D-printed syntactic foam created by UW-Madison engineers allows it to absorb a blow, then spring right back to its original shape.

Charles G. Salmon Associate Professor Pavana Prabhakar and PhD student Hridyesh Tewani designed the new foam. Its key feature: "embedded multilevel architectures," which build upon the tiny structures already present within syntactic foams. Syntactic foams are composites made up of tiny hollow spheres called "microballoons." These microballoons, which can be made of different materials like polymer or glass, give syntactic foams high strength relative to their low density, when integrated into a flexible polymer.

Prabhakar and Tewani tinkered with the structure even further, essentially creating an architecture around an architecture—using the microballoons as a guide to create larger, millimeter-scale gaps in the material.

Designing a material in this way could open opportunities for new lightweight, resilient materials with a wide range of potential applications. Tewani says the multilevel architecture—larger specific designed voids with smaller microballoon-sized voids already in the base material—create a "bounce-back" foam, which means it can take the force of an impact and return to its original shape.

That ability to take repeated impacts and bounce back to form means that applications for these materials could include many ways to protect an object from collisions—for example, a player's head inside an athletic helmet. Prabhakar says she and Tewani also envision the foams sandwiched between stiffer plates—such as in the hull of an airplane—during research.

"Let's say we have a bird strike with an airplane, or that you have a marine vessel that is going to have repeated ice sheet impacts in the Arctic," Prabhakar says. "We want the material to be able to absorb that energy and also return to its original shape. There are multi-use purposes for these architectures that we're developing—not just one time and done."

Out of the lab and onto the pavement: With wearable sensor, researchers study daily walking to mitigate tripping

Wearable devices like smartwatches and fitness bands that count a person's steps are ubiquitous today. Using a similar type of wearable sensor, UW-Madison engineers have developed a new method that goes beyond step counts: It allows researchers to see *how* a person walks in daily life.

"This is important for understanding how people with different abilities move in their everyday lives," says graduate student Katherine Heidi Fehr. "We can use our method to visualize and measure how different assistive devices and prostheses change how people walk and how the devices might affect their risk of tripping."

Currently, gait analyses are conducted in controlled lab settings where researchers use expensive equipment to record people as they walk. However, studies have shown that people tend to walk differently when they're being observed in a lab.

That's why Mead Witter Foundation Associate Professor Peter Adamczyk, Fehr and their collaborators set out to develop an easy, low-cost method to collect real-world data on how people walk in their everyday lives. The researchers described their method in a paper published in June 2024 in the journal *Scientific Reports.*

In their method, people go about their daily activities with a small motion sensor attached to their shoe. Graduate student and paper co-author Yisen Wang developed an improved method for reconstructing the motion of that sensor accurately enough to measure the details of its 3D movement, including rotation and height. The researchers combine the sensor data of the foot's movement with a 3D scan of the person's shoe. The resulting model allows the researchers to reconstruct and analyze how the person's foot moved throughout the day.

In particular, the researchers measure the foot clearance, or how close a person's foot gets to the ground while in the swing phase of walking. That's crucial for understanding and reducing the risk of trip-and-fall incidents for people with gait difficulties.

A big advantage of the method is that it allows researchers to analyze the movement of the whole foot. That's in contrast with other techniques that only consider the tip of the toe when the foot is swinging, providing a surrogate measure of foot clearance that might not be accurate, particularly for people with mobility challenges.

"Not everyone walks the same," says Fehr, the study's first author. "Some people might scuff the side of their foot or shuffle their feet. Our method reconstructs the whole shape of the foot so we can see and measure every point on the shoe. This gives us a more accurate measurement of the real-world foot clearance and a better understanding of an individual's risk of tripping."

Below left: The researchers' motion sensor is attached to a shoe. *Below right:* Associate Professor Peter Adamczyk and PhD student Katherine Heidi Fehr led the study. Photos: Tom Ziemer.

Project aims to improve additive manufacturing technologies

UW-Madison engineers are leading a new $9.1 million project funded by the U.S. Office of Naval Research that aims to enable broader usage of additive manufacturing technologies, especially in fabrication of mission-critical components.

Elmer R. and Janet Ambach Kaiser Professor Xiaoping Qian is the lead principal investigator on the project, which includes ME colleagues Harvey D. Spangler Professor Curt Bronkhorst, Charles Ringrose Associate Professor Lianyi Chen, Associate Professor and Grainger Institute for Engineering Faculty Scholar Shiva Rudraraju, Mead Witter Foundation Professor Krishnan Suresh, and Assistant Professor Jinlong Wu. Researchers from GE Aerospace Research, GE Additive, and Intact Solutions are also participating in the project.

An additive manufacturing technology called laser powder bed fusion can produce parts with complex geometries, but there is significant variability in dimensional accuracy, microstructures, porosity, residual stress and fatigue life in these parts. Such part-to-part and machine-to-machine variability has impeded effective and efficient qualification of additive manufactured parts, which has hampered adoption of these technologies.

The goal of this project is to develop computational methods for efficient qualification of additive manufactured parts and to exploit mechanical property variability in additive manufacturing, such as changes in microstructures and porosity, as increased design freedom for process-part co-design. Such process-part co-design will essentially treat process variability as a feature instead of an obstacle in quality control. The researchers aim to simultaneously optimize process control variables, part geometry and material properties in which material properties will be varied through additive manufacturing process control.

Professor Tim Osswald retires

After 35 years as a professor in the department, Tim Osswald retired in spring 2024. A world-renowned leader in the field of polymers, Osswald has long-lasting impact. Together with colleagues and graduate students, he created and co-directed the Polymer Engineering Center, and developed the most complete set of courses for undergraduates and graduates in the field of polymer engineering. He has published more than 400 papers and authored and co-authored 12 books, which have been translated into many languages. And he graduated more than 40 PhD students.

Over the years, Osswald has taught polymer processing, designing with polymers and polymer composites processing. His research in polymer engineering includes modeling and simulation in polymer processing, and engineering design with plastics, sustainability and biopolymers. He is an honorary professor of plastics technology at the University of Erlangen-Nuremberg in Germany and at the National University of Colombia. Osswald has served as a consultant to several industries, is one of the co-founders of The Madison Group, and is on the technical and scientific advisory boards of several companies.

Reflecting on his career at UW-Madison, Osswald says he will miss teaching his undergraduate courses, and he's proud of the numerous teaching awards he received over the years.

"In retirement, I will dedicate my time to writing our family history as well as to our natural rubber tree plantation in Colombia and natural rubber research company that I have created with my Colombian research partners," Osswald says.

Department news

Assistant Professor Luca Mastropasqua was selected by ARPA-E to join the first cohort of its Inspiring Generations of New Innovators to Impact Technologies in Energy 2024 program. The funding will support his efforts to transform the waste plastic upcycling process via the development of a solid-state electrochemical device for the controlled depolymerization of waste polymers.

The UW-Madison chapter of American Institute of Aeronautics and Astronautics soared to new heights in its second year competing in the Spaceport America Cup, taking second place in the Space Dynamics Laboratory payload challenge. Out of 152 teams in the 2024 competition, the UW-Madison chapter placed 58th overall.

Bjorn Borgen Professor Christian Franck received Research Forward funding to lead a project that seeks to understand how repetitive head impacts cause regional brain tissue injury and cognitive disfunction in younger athletes. Research Forward is intended to stimulate and support highly innovative, interdisciplinary and groundbreaking research at UW-Madison.

The Wisconsin Baja team had an excellent performance at the 2024 SAE off-road racing competition. The team placed second in the competition's main event, the four-hour endurance race.

Department of
Mechanical Engineering
UNIVERSITY OF WISCONSIN–MADISON

1513 University Ave., Room 2107
Madison, WI 53706
engineering.wisc.edu/me

A game-changing solution to a knotty problem in computational engineering

UW-Madison engineers have developed a remarkably easy-to-implement solution for handling tangled computational meshes—a major computational engineering challenge that can garble an object's shape.

To predict how various structures or components—a turbine, for example—will behave in real-world conditions, engineers use a simulation process called finite element analysis. A critical step in this process is "meshing," which involves breaking down the geometry of the structure into smaller, simpler pieces, called elements.

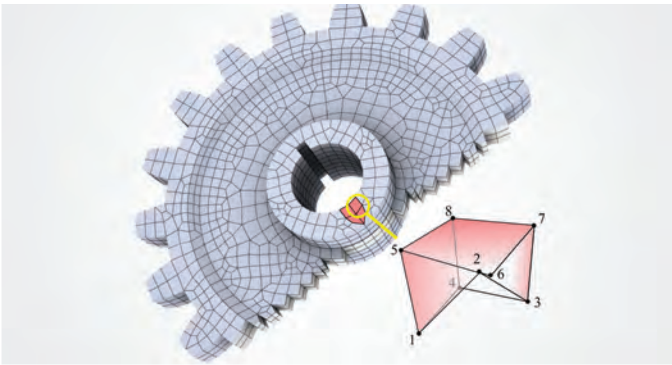
However, the process of generating or optimizing the mesh of a complex structure can sometimes result in smaller pieces with distorted shapes, known as "tangled" elements.

"If there is just one tangled element, it ruins the entire mesh, so we can't analyze that component and get trustworthy results," says Krishnan Suresh, the Mead Witter Foundation Professor. "Engineers usually need to throw out that tangled mesh and start from scratch to try to create a better mesh. An easy solution for dealing with tangled meshes is like a holy grail for the field."

Now, Suresh and recent PhD graduate Bhagyashree Prabhune have developed a novel approach, called the tangled finite element method, that can tackle tangled meshes and produce accurate results. Implementing the researchers' method involves making two simple changes to the software code, which ensures that the resulting solution is unambiguous, continuous and accurate.

Prabhune says this advance can enable companies to greatly speed up their simulation work. "Our new method is a game-changer," says Prabhune, who is now a postdoctoral research associate at Oak Ridge National Lab. "Generating a high-quality mesh without tangled elements requires lots of work by engineers and is extremely time-consuming, causing a big bottleneck for industry. But our method provides an easy way around this bottleneck."

The researchers have patented their invention through the Wisconsin Alumni Research Foundation.



An image of a computational mesh of a gear with a tangled element (circled). Credit: Bhagyashree Prabhune.