CYCLONE ENGINEERING RESEARCH

SPRING 2020

IOWA STATE UNIVERSITY

College of Engineering

On the cover:

Cyclone Engineer **Sarah Bentil** (pictured below, right) designed and fabricated a first-of-its-kind oxyacetylene-driven shock tube instrument to investigate how shock waves cause traumatic brain injuries.

Bentil's device accurately mimics the pressure versus time profile of shock waves that are generated when explosive devices are detonated. Her research aims to provide experimental data that will aid the design of new and better protective gear. Read more on page 4.

SPRING 2020 CONTENTS

ILLUMINATING INVISIBLE INJURIES WITH HIGH-IMPACT RESEARCH 4
GROWING COLLABORATION 6
3-D PRINTING CONCRETE 8
NONDESTRUCTIVE DIRECTION 10
EXPECT TURBULENCE 12
NEW MATERIALS FOR NUCLEAR REACTORS 13
NEWS BITES 14

W. Samuel Easterling
James L. and Katherine S. Melsa Dean of Engineering

Arun K. Somani
Associate Dean for Research
Anson Marston Distinguished Professor
Philip and Virginia Sproul Professor

Editor: **Breehan Gerleman**
Contributing Editors: **Madeline McGarry** and **Gillian Mohn**
Photography: **Christopher Gannon** and **Dan McClanahan**
Graphic Designer: **William Beach**
Contributing Designer: **Brittany Veto**
collegerelations@iastate.edu
www.engineering.iastate.edu/research

Copyright © 2020, Iowa State University of Science and Technology. All rights reserved.

Iowa State University does not discriminate on the basis of race, color, age, ethnicity, religion, national origin, pregnancy, sexual orientation, gender identity, genetic information, sex, marital status, disability, or status as a U.S. veteran. Inquiries regarding non-discrimination policies may be directed to Office of Equal Opportunity, 3410 Beardshear Hall, 515 Morrill Road, Ames, Iowa 50011, Tel. 515-294-7612, Hotline: 515-294-1222, email: eooffice@iastate.edu.

New Major in Cyber Security Engineering

In fall 2019, Iowa State launched a new bachelor's degree program in cyber security engineering, with nearly 80 students now enrolled. Students combine a solid foundation in computer engineering with a unique problem-solving mindset – so they can take on the complex cyber security challenges of the future.

ILLUMINATING INVISIBLE INJURIES WITH HIGH-IMPACT RESEARCH

The devastating effects of traumatic brain injuries caused by flying, penetrating objects following a blast are well documented. What remains unknown are the specifics of how shock waves, created immediately after detonation of explosive devices, damage the brain.

Sarah Bentil, assistant professor of mechanical engineering, leads a research team that is illuminating the invisible: non-penetrative brain injuries suffered by those returning from combat due to shock waves.

Sarah Bentil, assistant professor of mechanical engineering

Brain as a material

Bentil's expertise is characterizing how soft materials deform in response to force or impact, including shock waves, and predicting the material's behavior using a mathematical model. Her research uses an approach that focuses on the brain as a material. Over time, her team's work will evolve to shed light on how shock waves cause invisible brain injuries that cannot be detected from MRI scans.

Researchers in Bentil's line of work often use shock tubes to mimic blasts, but not all of them are created equally.

Enter the oxyacetylene-driven shock tube – a device that Bentil's group designed and fabricated for experiments investigating traumatic brain injury mechanisms caused by the propagating shock wave. Unlike conventional compression-driven shock tubes, which cannot fully mimic the pressure versus time profile of a shock wave, an oxyacetylene-driven shock tube can accurately generate the type of shock waves created when an explosive device is detonated.

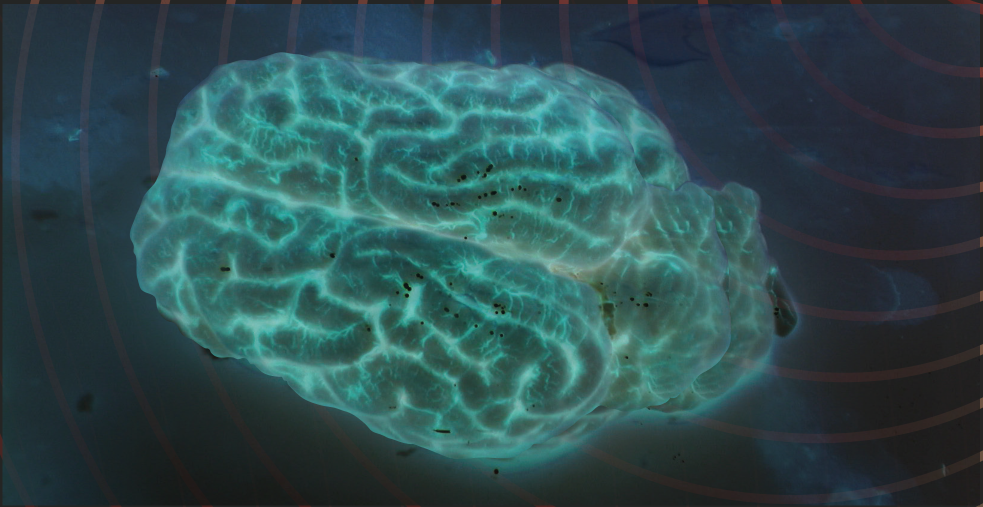
The 3-inch diameter shock tube is comprised of a 1-foot driver section filled with oxygen and acetylene, which is connected to a 15-foot long driven section with an end that is open to the atmosphere. The driver and driven sections are separated by a diaphragm. By igniting the oxygen and acetylene in the driver section, the diaphragm ruptures and creates the shock wave.

"We have conducted shock wave experiments with brain tissue and are able to understand how the brain surface changes its shape due to the propagating wave," said Bentil. "We have also found that structural changes due to the propagating shock wave has caused the brain to have a different mechanical response. Essentially, the brain becomes less stiff after being exposed to the shock wave."

Accessible, new instrument

The oxyacetylene-driven shock tube more accurately replicates a blast wave, is just as cost effective as compression-driven shock tubes, and is not as expensive and dangerous to operate as blast-driven shock tubes. Bentil's oxyacetylene-driven shock tube is a new, pragmatic option that makes blast-induced traumatic brain injury research more accessible to researchers because it does not require detonating an explosive.

"The oxyacetylene-driven shock tube is built from commercially-available parts. So if a component of the shock tube needs to be replaced, I can go to the local hardware store and easily buy what I need to replace it," Bentil said.



Sarah Bentil treats the brain as a material, examining its response to shock waves caused by explosive blasts.

Bentil says that Iowa State University is one of the first academic institutions to use an oxyacetylene-driven shock tube for blast impact research.

Meeting in the middle

Bentil aims to quickly and widely share experimental data from the shock tube experiments with others in the brain injury research community. With increased understanding of the brain's response to shock waves, Bentil hopes that improved personal protective gear can be designed to prevent or mitigate blast injuries.

"Most people work on addressing questions related to traumatic brain injuries from the outside-in, such as how to design new helmet liners to mitigate the effects of the shock wave. However, how the brain is actually responding to the shock wave remains unknown," Bentil said. "We're working on the problem from the inside-out – and it is my hope that the entire brain injury research community will merge in the middle."

Bentil's project is supported by the Roy J. Carver Charitable Trust of Muscatine, Iowa.

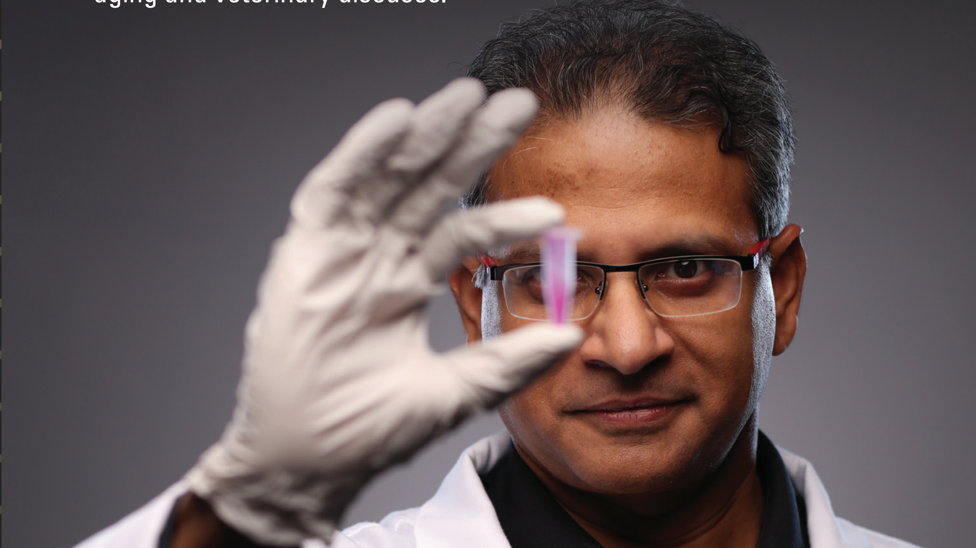
Nanovaccine innovator named to National Academy of Inventors

Cyclone Engineer **Balaji Narasimhan** has been named to the National Academy of Inventors for his innovative work in nanomedicines and biomedical engineering.

Narasimhan, an Anson Marston Distinguished Professor in Engineering and Vlasta Klima Balloun Faculty Chair in chemical and biological engineering, works at the intersection of materials science, nanotechnology and medicine.

His latest projects include studies of a universal nanovaccine for influenza, an immunotherapy treatment for pancreatic cancer, a new nanovaccine for respiratory syncytial virus (RSV), nanomedicine-based methods to overcome antimicrobial resistance by some pathogens and nanovaccines to treat older adults.

Narasimhan directs the Nannovaccine Institute, a consortium of 67 researchers at 20 universities, research institutes, national laboratories and companies, led by Iowa State University. The institute uses an interdisciplinary approach to developing nanovaccines and nanotherapeutics – which are needle-free, available in single doses and room-temperature stable – for respiratory infections, neural disorders, tropical diseases, cancer, aging and veterinary diseases.



GROWING COLLABORATION:

Optimization and machine learning meet plant genomics

Lizhi Wang, associate professor of industrial and manufacturing systems engineering, is applying process optimization and machine learning to improve crops' adaptability to new environmental conditions.

Wang, also an Iowa State Plant Sciences Institute Faculty Scholar, serves as the principal investigator for the project supported by a $2 million grant from the National Science Foundation.

Wang, along with three other Iowa State faculty members – **Guiping Hu**, associate professor of industrial and manufacturing systems, **Sotirios Archontoulis** and **William Beavis**, both Iowa State agronomy researchers – is creating new algorithmic models that make more accurate predictions about plant phenotypes. The research provides insight into the observable characteristics of plants, including yield, foliage color and height.

The team also includes the students of Wang's fellow faculty members along with industry collaborators from Corteva, Syngenta and Kromite. Wang says using engineering methods to study plant genomics is an uncommon, but promising, interdisciplinary collaboration.

"Resource allocation decisions in the plant breeding process have traditionally been made through trial and error," Wang said. "But, the efficiency of such decisions can be greatly optimized using deep Q-learning, a type of reinforcement learning algorithm."

Wang says the challenge of the interdisciplinary collaboration is engineers' understanding of plant genomics and plant scientists' understanding of engineering methods. When the understanding is mutual, both engineering and plant genetics experts can engage in a productive exchange of ideas, leading to new discoveries.

"We have been working on the problem for a few years, and we realized that engineering principles can be applied to genomic selection and significantly improve the efficiency of plant breeding," Wang said.

With changes in global climate and environmental conditions, Wang and his team aim to optimize plant genetics to maximize resilience and expedite adaptation to changing environments.

Competition leads to superior models

Wang works to integrate his research into the undergraduate and graduate courses he teaches. Students in his industrial manufacturing and systems engineering classes get a unique introduction to the study of plant genomics and other nontraditional applications of engineering principles.

In most related research today, optimizing genomics is based on finding pairs with the highest genetic estimated breeding value (GEBV). In Wang's class competitions, students have identified ways to further improve his methodology. A winning proposal from Wang's students took his algorithmic models one step further by accounting for the complementarity of breeding pairs and generational differences.

"When the results were back from the student projects, I was so amazed," Wang said. "They were really out-of-the-box designs, and they are not like any algorithm you have seen in the literature."

The novel and innovative findings generated from Wang, his team and his students will continue to drive the future trajectory of the research, solidifying the nexus between plant genetics and engineering.

> "Resource allocation decisions in the plant breeding process have traditionally been made through trial and error, but the efficiency of such decisions can be greatly optimized using deep Q-learning, a type of reinforcement learning algorithm."

Lizhi Wang
associate professor of industrial and manufacturing systems engineering

Iowa State University

Plant Sciences Institute

The Plant Sciences Institute (PSI) builds on Iowa State University's longtime international prominence in plant sciences research – with an eye on the future challenge of feeding and fueling a growing world population.

PSI's focus is predictive phenomics: understanding the effects of genotype and environment on plant growth and development sufficiently well to be able to predict with reasonable accuracy the phenotypes (plant traits) of a given genotype in a given environment. The overall goal is to increase the efficiency of breeding and crop productivity.

While PSI rests on the foundation of Iowa State's unique concentration and variety of expertise in plant sciences, researchers from engineering, statistics and beyond contribute to groundbreaking multidisciplinary projects.

Cyclone Engineers with expertise in materials science and engineering, computer and electrical engineering, mechanical engineering, industrial and manufacturing systems engineering and more have served as PSI Faculty Scholars, contributing specialized engineering techniques to data-driven plant breeding solutions.

3-D PRINTING CONCRETE
Rapid Solutions with a Steady Material

If 3-D printing can quickly and efficiently create machine parts, could it also quickly and efficiently create bridges and buildings after natural disasters? **Kejin Wang**, Wilson Professor of Engineering in civil, construction and environmental engineering, is leading advanced research in the emerging field of 3-D concrete printing. She aims to add 3-D concrete printing to civil and construction engineers' toolbox.

Unique qualities promise strength

The applications for 3-D concrete printing are expansive, ranging from residential housing and bridges to architecture and aesthetic structures. In events where structural integrity of a building or bridge has been compromised, 3-D concrete printing may be a strong solution to building in challenging situations, even with the required cure time.

"Unlike polymers and metals, concrete needs sufficient time to solidify and to be capable of holding the weight of the layers deposited above," Wang said.

Though the amount of time required for concrete to solidify exceeds other 3-D printing materials, its qualities in strength and detail surpass those of metals and polymers.

Formulating the perfect recipe

As 3-D concrete printing gains popularity, the central challenge of Wang's research is ensuring concrete flow is optimal while retaining an unmalleable shape during the hardening phase.

"If the stiffness or strength of the printed concrete does not develop promptly, the printed objects may slump, distort or collapse with time," Wang said.

So, Wang and her research team are applying rheological concepts to optimize concrete flows and shape stability.

To improve cement flows for printing, a variety of chemical agents are used to adjust the rheological behavior of the material. The recipe for success in formulating the perfect concrete mixture is balancing flow ability with solidification time. Dispersants and thixotropic agents function to expedite the flowability while preventing separation of materials in the mixture and enhancing shape stability of the printed products.

Wang and her team also assess the resulting quality of the printed material. Using different printing speeds and cement mixtures, post-assessments characterize how the shape and geometry of the concrete changes, as well as deformities that emerge following printing.

The level of detail that is provided by concrete along with competitive quality makes the material and technology advantageous. Wang hopes that 3-D printing techniques can provide comparable quality and texture to other 3-D printed materials.

"The time-dependent qualities of concrete demand breakthroughs in concrete mix proportioning, processing, and rapidly and effectively evaluating methods for the quality assurance of the printed products," Wang said.

Kejin Wang
Wilson Professor of Engineering in civil, construction and environmental engineering

Iowa State University

Institute for Transportation

Iowa State's Institute for Transportation (InTrans) is a hub of local, regional and national transportation-focused research, education, workforce development and technology transfer.

InTrans began in 1983 as a technical assistance program for Iowa's rural transportation agencies. It has since grown to encompass 15 centers and programs and a variety of technology transfer and professional education initiatives.

InTrans' primary sponsor is the Iowa Department of Transportation, but partners from nearly every state and many nations around the world collaborate with InTrans on pressing challenges in infrastructure, safety, mobility, data analytics and resiliency, construction management and outreach education.

More than 100 Iowa State faculty and staff members work with InTrans, and from 200 to 250 student assistants from several ISU departments conduct research while working closely with university faculty.

NONDESTRUCTIVE DIRECTION

NEW CENTER DIRECTOR, CONTINUED NATIONAL LEADERSHIP

Reza Zoughi, a research and teaching leader in nondestructive evaluation, has joined Iowa State University as the director of the Center for Nondestructive Evaluation and the Kirby Gray (Battelle) Chair in Engineering in the Department of Electrical and Computer Engineering.

Zoughi, a Fellow of both the Institute of Electrical and Electronics Engineers and the American Society for Nondestructive Testing, has published more than 640 journal papers, conference proceedings and technical reports as well as a book titled “Microwave Nondestructive Testing and Evaluation Principles.” He is also credited with 18 U.S. patents, with several issued internationally.

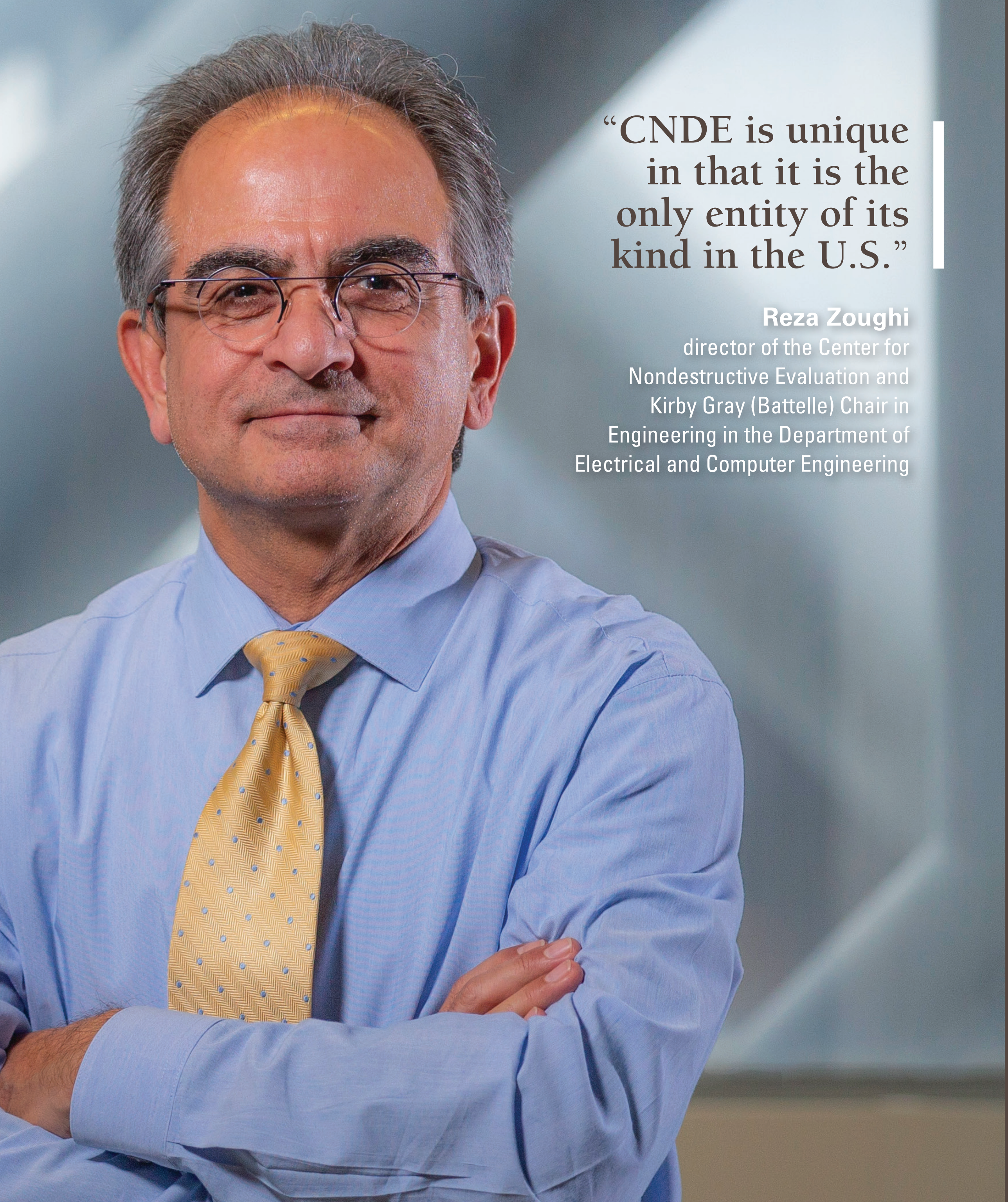
Prior to joining Iowa State, Zoughi was with the Missouri University of Science and Technology (previously Missouri-Rolla) as the Schlumberger Distinguished Professor and director of the Applied Microwave Nondestructive Testing Laboratory.

Under his leadership, the laboratory became well known for its excellence in microwave and millimeter wave nondestructive testing and evaluation.

Zoughi will now lend his NDE expertise to Iowa State’s U.S.-leading Center for Nondestructive Evaluation.

“I’m excited to be leading the Center for Nondestructive Evaluation’s longtime mission: actively promoting and guiding the future of the NDE discipline; discovering and translating new science to the NDE discipline; developing innovative NDE technologies and transitioning them to the NDE community; educating NDE experts and scientists; and addressing broader global NDE needs.

“CNDE is unique in that it is the only entity of its kind in the U.S. As such, CNDE’s role and importance in preserving the health, functionality and safety of our nation’s aerospace, space, transportation and civil infrastructure must become and remain a national priority,” said Zoughi.



> "CNDE is unique in that it is the only entity of its kind in the U.S."

Reza Zoughi
director of the Center for Nondestructive Evaluation and Kirby Gray (Battelle) Chair in Engineering in the Department of Electrical and Computer Engineering

IOWA STATE UNIVERSITY

Center for Nondestructive Evaluation

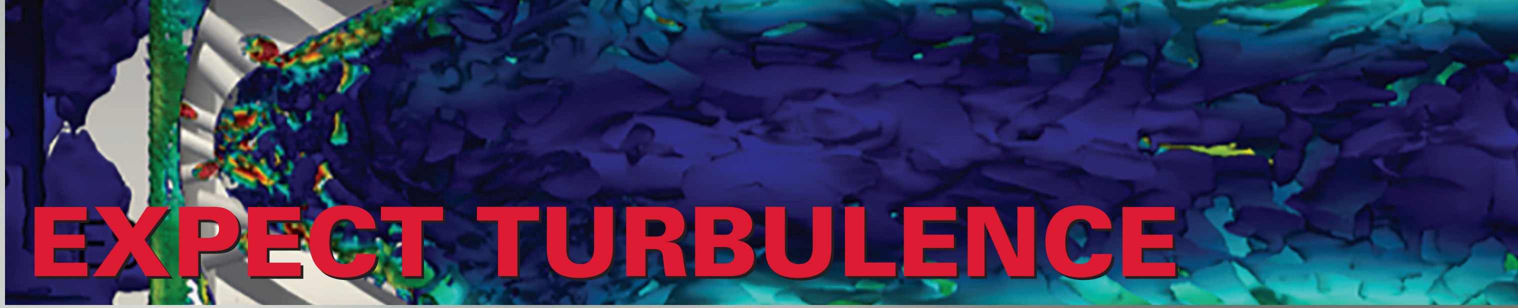
Iowa State's Center for Nondestructive Evaluation (CNDE) is the preeminent national leader in nondestructive evalution fundamental science, technology and educational innovations – and engineering know-how for "all things NDE."

With more than 30 years of success, CNDE engineers combine fundamental understanding of inspection physics, innovative measurement techniques and accurate simulation tools to ensure safety and efficiency of many critical engineered systems.

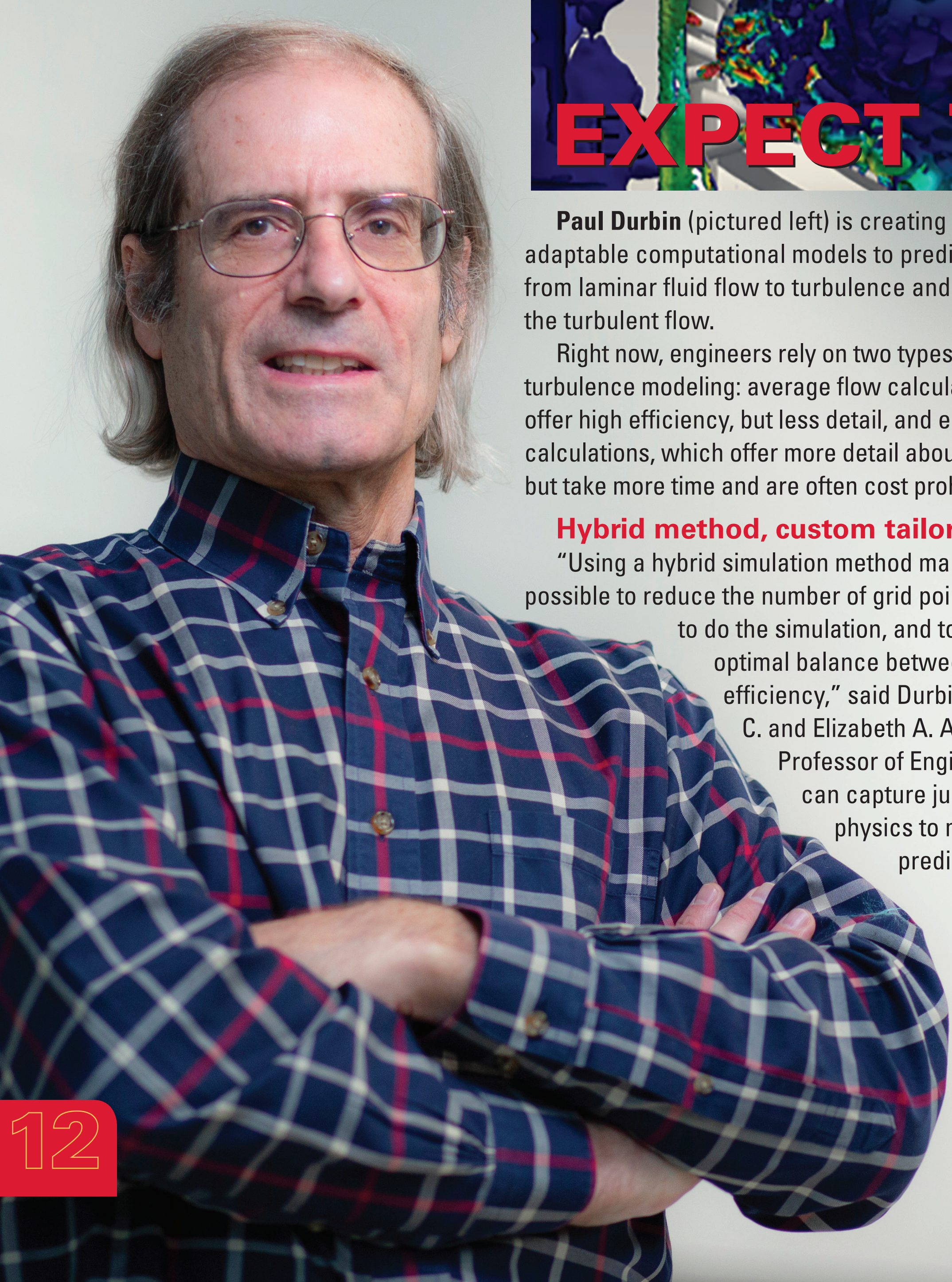
CNDE's approach has led to commercialization of new methods in major inspection types, inspection system developments applied to metals, ceramics and composites, and successful collaborations with a large and diverse group of research partners.

CNDE was established in 1985 as a National Science Foundation Industry/University Cooperative Research Center. With over 30 scientists and engineers, CNDE provides cost-effective tools and solutions to industry leaders in aerospace, defense systems, energy, infrastructure, technology and petrochemicals.

CNDE also helps train the next generation of nondestructive evaluation engineers through Iowa State's undergraduate minor and graduate certificate in NDE.



EXPECT TURBULENCE



Paul Durbin (pictured left) is creating new hybrid, adaptable computational models to predict transitions from laminar fluid flow to turbulence and to simulate the turbulent flow.

Right now, engineers rely on two types of turbulence modeling: average flow calculations, which offer high efficiency, but less detail, and eddy-resolving calculations, which offer more detail about turbulence, but take more time and are often cost prohibitive.

Hybrid method, custom tailored

"Using a hybrid simulation method makes it possible to reduce the number of grid points required to do the simulation, and to find the optimal balance between detail and efficiency," said Durbin, Joseph C. and Elizabeth A. Anderlik Professor of Engineering, "We can capture just enough physics to make reliable predictions."

The goal is for Durbin's hybrid model to adapt itself to the specific mechanics of a simulation, automatically balancing how much of each type of turbulence model is needed to reach the sweet spot between accuracy of eddy-resolving and efficiency of average calculations.

"Some computational algorithms adapt their grid to the fluid mechanics, but in our case we are working to make the model adapt to whether the grid can resolve the turbulent eddies or not," said Durbin. "Our model senses eddies and adjusts itself. If the grid is really fine, it can use more of the eddy-resolving model, but if the grid is coarse, it needs more of the average model."

Impact across engineering

Durbin is testing his new approach on the National Science Foundation's XSEDE supercomputers and applying the hybrid turbulence model to questions of ship hulls' roughness and turbulence for the U.S. Navy.

Since turbulence considerations span many engineering disciplines, his new hybrid model has the potential for wide impact.

"Questions about turbulence are important in engineering problems ranging from designing small engines, to aircraft, to wind turbine blades," says Durbin. "Engineers both seek to cause turbulence and to prevent it. Either way, having more efficient, accurate simulations will improve designs."

“I’m contributing novel nondestructive evaluation characterization techniques so we can develop new materials for accident-tolerant nuclear fuel rods.”

Trishelle Copeland-Johnson (pictured right) is a Ph.D. student in materials science and engineering. She was recently awarded an American Society for Nondestructive Testing Fellowship for her research in new materials for nuclear reactors.

Safer, stronger fuel rod materials

“I am involved with disaster-based research based on the explosions observed at the Fukushima Daiichi Power Plant in 2011. These explosions were attributed to the failure of a protective barrier layer that grows on the encasements, which we call claddings, used to seal radioactive fuel to form a nuclear fuel rod. The barrier layer shields the fuel rod from the extreme environment inside the reactor.

“I am contributing to the development of a new class of materials to construct fuel rods with ‘accident-tolerant’ capabilities, in which the barrier layer can withstand the emergency conditions observed at Fukushima, including temperatures of over 1000 C for extended periods inside the nuclear reactors, providing operators additional time to restore normal operations.”

Novel, nondestructive techniques

“Here at Iowa State, I’m a member of **Nicola Bowler’s** research group that specializes in electromagnetic nondestructive evaluation techniques. My background is characterization of materials at the nano- and microscale with techniques like microscopy and X-ray diffraction.

“The ASNT Fellowship provides me with an opportunity to intersect my expertise with that of my research group to develop novel NDE techniques for measuring the growth of barrier layers grown on accident-tolerant fuel rod claddings.”

Find your champions

“Find people who will advocate and support you, when others doubt you because of their own implicit biases about the competence of women of color who pursue technical fields. At a predominately white institution like Iowa State, those allies will most likely not look like you, but regardless they are genuinely good people who want you to succeed.”

Sustainable Midwest cities

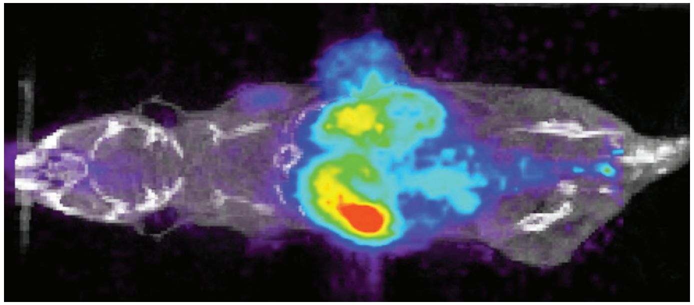
Dense urban areas use more energy, water and food resources than they can produce, forcing them to rely on external sources. But Cyclone Engineers are imagining bold new ways to make Midwestern cities more self-reliant.

Michael Dorneich, associate professor of industrial and manufacturing systems engineering, and **Baskar Ganapathysubramanian**, professor of mechanical engineering, are part of a $2.5 million, multidisciplinary National Science Foundation project to study how to bolster local food production in Des Moines, Iowa, and how different approaches could impact nutrition, waste and the environment.

Smart imaging for cancer immunotherapies

Rizia Bardhan is developing new techniques to better predict and evaluate the effectiveness of immunotherapies used to treat cancer.

Bardhan, associate professor of chemical and biological engineering, pairs encoded gold nanoparticles with position emission tomography (PET) and Raman spectroscopy to accurately detect both PD-L1 immune biomarkers and CD8 lymphocytes in tumors. Testing with melanoma tumors in animal models demonstrated that the new imaging probe successfully distinguished between “responders” and “nonresponders” early in the PD-L1-blocking immunotherapy regimen.

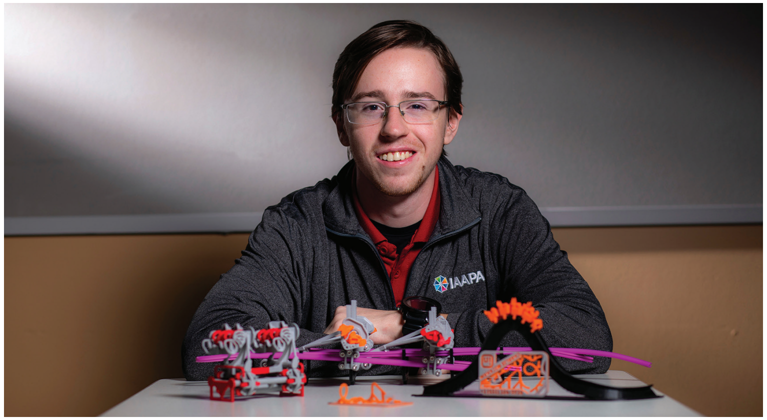


Wind gardens power rural communities

If huge wind farms provide electricity to far away cities, could smaller wind “gardens” do the same for nearby rural communities? A team of Cyclone Engineers are leading a $1.2 million Department of Energy project to design optimization models and control algorithms that perfect the connections between distributed windmills and rural, local grids.

Engineering adrenaline rush

Charlie Wickham (pictured below), a senior majoring in mechanical engineering, has braved 250 roller coasters around the world and interned at top ride makers and amusement parks. Now he's bringing his experience and enthusiasm for safe, exciting ride design back to campus, using 3-D printing prototyping to visualize roller coaster designs. He also started the Theme Park Engineering student club that comes together to learn more about the amusement park industry.



Dishing up more food, less waste

Dirk Maier, professor of agricultural and biosystems engineering, and **Tom Brumm**, associate professor of agricultural and biosystems engineering, in partnership with the Foundation for Food and Agricultural Research and the Rockefeller Foundation, have launched the Consortium for Innovation in Post-Harvest Loss and Food Waste Reduction. The consortium brings together leaders and experts from across the globe to work with industry and nonprofits to address social, economic and environmental impacts from food waste and loss.

"Successfully cutting food loss and waste in half would avoid the need to convert an area the size of Argentina into agricultural land," said Maier. "It would also lower greenhouse gas emissions by 1.5 gigatons per year by 2050."

Zhaoyu Wang, assistant professor of electrical and computer engineering, **Anne Kimber**, director of Iowa State's Electric Power and Research Center, and **Venkataramana Ajjarapu**, professor of electrical and computer engineering, will help rural utilities leverage distributed wind turbines for normal operation – and to provide emergency power in outages.

Iowa State University
College of Engineering
4100 Marston Hall
533 Morrill Road
Ames, Iowa 50011-2103

Blossoming into new flexible electronics

Cyclone Engineers led by **Martin Thuo**, assistant professor of materials science and engineering, are using heat-free, liquid-metal particles to print electronic lines and traces on all kinds of materials, everything from gelatin to leaves to rose petals. The technology creates flexible electronics that could be used in monitoring crops, collecting biological data or tracking buildings' structural integrity.

Factor Analysis podcasts dig deeper into current events via in-depth conversations with Cyclone Engineering researchers, students and alumni. Available wherever you listen to podcasts.

engineering.iastate.edu/podcast