

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

RESEARCH IMPACT



THE OHIO STATE UNIVERSITY
COLLEGE OF ENGINEERING

2021

Message from the Chair

Rob Siston

The Department of Mechanical and Aerospace Engineering at The Ohio State University builds on its diversity of people and ideas to cultivate a range of advancements in mechanical, aerospace and nuclear engineering.

From gears to cancer research, our mechanical engineers are experts in an array of specialty areas. Our strengths in both aeronautical and astronautical engineering boost the impact of our aerospace engineers. And, with an on-site nuclear reactor—and high-achieving graduates throughout industry and government—our nuclear engineers value collaboration.

To showcase the unique achievements of each of our programs, we have created the publication: Research Impact: Mechanical. Inside you will see samples of our advancements in mechanical, aerospace and nuclear engineering over the past year.

We unveiled methods for designing DNA robots in minutes rather than days (page 3), investigate the intersection of cybersecurity and mobility, to promote safety in the next generation of vehicles (page 7), identified a promising material for future devices that could turn heat on and off with no moving parts (page 9) and developed a DNA-based biosensing device for rapid diagnostics of COVID-19, as well as other viral diseases. (page 18.)

All of this was accomplished with our talented students, who continue to be our primary focus. They are involved in every facet of our research.

I invite you to read on to learn about our recent cutting-edge innovations.

Rob Siston
Chair, Mechanical and Aerospace Engineering
Professor, Mechanical and Aerospace Engineering



Cover: An MAE graduate student examines a specimen in the newly-installed atomic force microscope (AFM) in Scott Lab. Read more: Page 11

DEPARTMENT AT A GLANCE

DEGREES CONFERRED

Academic Year 2020- 2021

BS	234 MECHANICAL	76 AEROSPACE	
MS	67 MECHANICAL	15 AEROSPACE	3 NUCLEAR
PHD	24 MECHANICAL	2 AEROSPACE	6 NUCLEAR

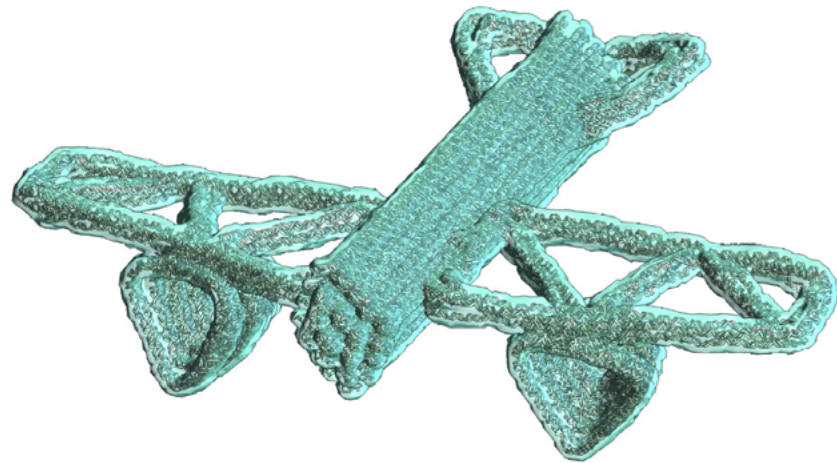
STUDENT ENROLLMENT

Autumn Semester 2020

BS	572 ME MAJOR	607 ME PRE-MAJOR	168 AE MAJOR	312 AE PRE-MAJOR
MS	83 MECHANICAL	27 AEROSPACE	2 NUCLEAR	
PHD	124 MECHANICAL	34 AEROSPACE	22 NUCLEAR	



DNA robots designed in minutes instead of days



This "airplane," made of strands of DNA, is 1000 times smaller than the width of a human hair.

Someday, scientists believe, tiny DNA-based robots and other nanodevices will deliver medicine inside our bodies, detect the presence of deadly pathogens, and help manufacture increasingly smaller electronics.

Researchers took a big step toward that future by developing a new tool that can design much more complex DNA robots and nanodevices than were ever possible before in a fraction of the time.

In a paper published April 19, 2021 in the journal Nature Materials, researchers from The Ohio State University – led by former engineering doctoral student **Chao-Min Huang** – unveiled new software they call MagicDNA.

The software helps researchers design ways to take tiny strands of DNA and combine them into complex structures with parts like rotors and hinges that can move and complete a variety of tasks, including drug delivery.

Researchers have been doing this for a number of years with slower tools with tedious manual steps, said **Carlos Castro**, co-author of the study and associate professor of mechanical and aerospace engineering at Ohio State.

"But now, nanodevices that may have taken us several days to design before now take us just a few minutes," Castro said.

And now researchers can make much more complex, and useful, nanodevices.

"Previously, we could build devices with up to about six individual components and connect them with joints and hinges and try to make them execute complex motions," said study co-author **Hai-Jun Su**, professor of mechanical and aerospace engineering at Ohio State.

"With this software, it is not hard to make robots or other devices with upwards of 20 components that are much easier to control. It is a huge step in our ability to design nanodevices that can perform the complex actions that we want them to do."

The software has a variety of advantages that will help scientists design better, more helpful nanodevices and – researchers hope – shorten the time before they are in everyday use.

One advantage is that it allows researchers to carry out the entire design truly in 3D. Earlier design tools only allowed creation in 2D, forcing researchers to map their



Castro

creations into 3D. That meant designers couldn't make their devices too complex.

The software also allows designers to build DNA structures "bottom up" or "top down."

In "bottom up" design, researchers take individual strands of DNA and decide how to organize them into the structure they want, which allows fine control over local device structure and properties.

But they can also take a "top down" approach where they decide how their overall device needs to be shaped geometrically and then automate how the DNA strands are put together.

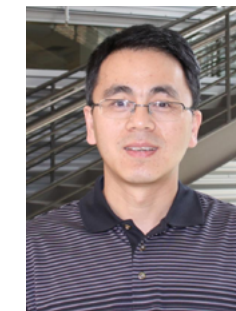
Combining the two allows for increasing complexity of the overall geometry while maintaining precise control over individual component properties, Castro said.

Another key element of the software is that it allows simulations of how designed DNA devices would move and operate in the real world.

"As you make these structures more complex, it is difficult to predict exactly what they are going to look like and how they are going to behave," Castro said.

"It is critical to be able to simulate how our devices will actually operate. Otherwise, we waste a lot of time."

As a demonstration of the software's ability, co-author Anjelica Kucinic, a doctoral student in chemical and biomolecular engineering at Ohio State, led the researchers in making and characterizing many nanostructures designed by the software.



Su

Some of the devices they created included robot arms with claws that can pick up smaller items, and a hundred nanometer-sized structure that looks like an airplane (The "airplane" is 1000 times smaller than the width of a human hair).

The ability to make more complex nanodevices means that they can do more useful things and even carry out multiple tasks with one device, Castro said.

For example, it is one thing to have a DNA robot that, after injection into the bloodstream, can detect a certain pathogen.

"But a more complex device may not only detect that something bad is happening, but can also react by releasing a drug or capturing the pathogen," he said.

"We want to be able to design robots that respond in a particular way to a stimulus or move in a certain way."

Castro said he expects that for the next few years, the MagicDNA software will be used at universities and other research labs. But its use could expand in the future.

"There is getting to be more and more commercial interest in DNA nanotechnology," he said. "I think in the next five to 10 years we will start seeing commercial applications of DNA nanodevices and we are optimistic that this software can help drive that."

Joshua Johnson, who received his PhD at Ohio State in biophysics, was also a co-author of the paper.

The research was supported by grants from the National Science Foundation.

This news first appeared on news.osu.edu and was written by Jeff Grabmeier.



Creating waves in solids: MAE collaboration on materials research

Mechanical and Aerospace Engineering Professor, **Marat Khafizov**, and MAE graduate student **Yuzhou Wang** took part in a collaborative project with researchers from Idaho National Laboratory (INL). The multi-institutional team worked to demonstrate how sound waves generated by light can be used to observe materials' inner structure. This discovery enables future research to monitor a material's inner structure while it is being subjected to extreme conditions.

The research demonstrated a new method to measure crystallite orientation in a transparent ceramic material. Khafizov said the basic idea behind this approach is "similar to dropping a rock on the surface of water and watching wave ripples propagate on the surface."

While waves on the surface of the water are visible to the eye, the acoustic waves resonating inside the solid material are a result of atomic vibrations. These require a different approach to detect.

"Instead of a rock, we use a very short laser pulse focused through a microscope objective to launch the wave inside a solid material," said Khafizov. "To observe the ripples, we use a different laser pulse."

The second laser pulse is used to detect any changes in optical transparency of the material that can occur as the wave ripples through the solid. The unique aspect of measuring these waves in solids is that unlike liquids, which only produce longitudinal waves, solids can produce three different types of waves. These wave

types are determined by the different directions atoms vibrate as the wave propagates.

Much of the hands-on work was performed by nuclear engineering graduate student, Yuzhou Wang. Other portions of the measurements were done by Wang at experimental facilities in Idaho National Laboratory during

his summer internship. Wang took these measurements and brought them back to Columbus for interpretation as part of his PhD dissertation.

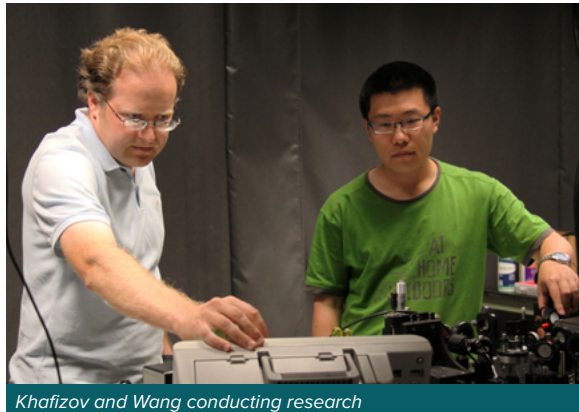
Khafizov said the chance to perform research with INL is a valuable experience for Ohio State students. Alongside scientific leaders in laser ultrasonics, graduate students worked to recognize and identify new information from the experiments. The opportunity to spend time at INL and work with their researchers

is made possible in part by Ohio State's participation in the INL National University Consortium.

The results of this research are already being implemented in new projects. One use is inspecting material grains as temperature changes, to understand limits of material thermal conductivity.

According to Khafizov the results of the research benefit multiple areas. It could allow development of ceramic materials that advance clean and secure energy systems. The project could also be applied to defense by providing optical ceramics for high powered lasers, and ceramic armor.

Written by Sam Cejda



Khafizov and Wang conducting research

Preparing the nation for drones carrying cargo and people

In support of the Ohio Department of Transportation, the College of Engineering will play a key role in NASA's recently announced Advanced Air Mobility National Campaign. The effort includes five government entities collaborating to determine how cargo-carrying drone and passenger-carrying air taxi services can be integrated into civic transportation plans.

The State of Ohio's project will incorporate multiple use cases for personal travel and delivery of goods. Its winning proposal outlines test applications in health care delivery, air taxi or air metro, and regional air cargo transport. Led by the Ohio Unmanned Aircraft Systems (UAS) Center, the team is comprised of aircraft manufacturers, operators, and airspace service providers and suppliers, regional and city planning organizations, health care networks, and other academic institutions.

The regional campaign activities will take place through summer of 2022, each including a series of at least four workshops where experts from the localities and NASA's Advanced Air Mobility (AAM) mission will work on updating local plans and creating new plans that might be needed to enable AAM.

"What's the best way for a local government to implement an AAM system that is equitable, sustainable, and integrated with its other transportation systems? Answering that is a big part of what this is all about," said Nancy Mendonca, NASA's deputy AAM mission integration manager.

Ohio State's involvement is spearheaded by the College of Engineering's Aerospace Research Center (ARC), located adjacent to the university's airport in northwest Columbus. ARC faculty and staff specialize in the design and deployment of advanced autonomous systems, including complex unmanned traffic management (UTM) systems key to enabling the AAM concepts sought by NASA. Since 2018, Department of Mechanical and



Research Scientist Matt McCrink (right) installs a low-altitude surveillance radar on a water tower in Marysville, Ohio.

Aerospace Engineering Professor **Jim Gregory** and ARC Research Scientist **Matt McCrink** have studied the use of drones to monitor traffic and roadway conditions from the air along the U.S. 33 Smart Mobility Corridor in central Ohio. Funded by the Ohio Department of Transportation, the project includes a system of sensors and communication equipment enabling unmanned traffic management.

"The team and technologies we've developed in support of this work will allow us to pursue more complex operations with more capable vehicles to expand access to, and the availability of AAM," said McCrink. "However, much work is still required to ensure that this new technology is safe and can reliably meet the needs of consumers and communities."

Home to more than 550 aerospace companies and three of the nation's premier aerospace centers— NASA Glenn Research Center, NASA Neil A. Armstrong Test Facility and Air Force Research Laboratory at Wright Patterson Air Force Base—Ohio is the nation's largest aerospace industry supplier, with a workforce of more than 38,000 in the aviation and aerospace industry.

Reverse engineering an experimental drone – with a new speed record goal in sight

The Aerospace Research Center (ARC) has long been a hub of record-setting research. Among the current projects undertaken by faculty and students alike is one by graduate student **Kali Boyd**, involving reverse engineering a model of an aircraft to predict the flight characteristics of an unmanned aerial vehicle (UAV) that will be used as an experimental aircraft platform.

Headed by **Cliff Whitfield**, PhD, director of the Flight Vehicle Design and Testing Group, the project aims to push the boundaries of aircraft configuration research and development. As such, Whitfield needed a fast learner to take on the task of researching this UAV. Boyd, having graduated in 2019 with a bachelor's degree

in mechanical engineering from The Ohio State University, was the perfect fit.

Boyd's project fits into a larger collaborative investigation undertaken by Whitfield and the Aerodynamic Flow Control and Advanced Diagnostics (AFCAD) research group at ARC. In 2017, AFCAD set a world record by flying a UAV at an average of 147 mph for 17 minutes, and

this record hasn't been broken since. Whitfield and team hope to create a new UAV to be used in future research, including breaking that speed record.

Boyd focuses her research on predicting the dimensions the UAV should have by examining a model. The model, which had already been built when Boyd took on the project, is one-fifth of the size of the proposed UAV, and it is intended primarily for testing the flight characteristics of the aircraft in the Battelle Subsonic Wind Tunnel at ARC before committing the resources to build the full-size one. Another model, a little bigger at one-third of the size, will be tested outdoors during later stages of the project.

Although Boyd's project isn't over yet, she's already begun writing a thesis on her findings, which she will present to her committee.

Reflecting on her time reverse engineering this model, Boyd says, **"I've learned a lot from doing this project." She's confident that her experience will set her up for success in her career after graduation. "If I saw something on a different aircraft, I would be able to know why the aircraft was built that way."**

Boyd already has a job lined up after graduation: she'll go on to work for the National Air and Space Intelligence Center in Fairborne, Ohio, putting her new knowledge to good use.

Read more about Boyd's project at go.osu.edu/RI_Boyd

Written by Beck Schulz



Kali Boyd displays the one-fifth-size UAV model.

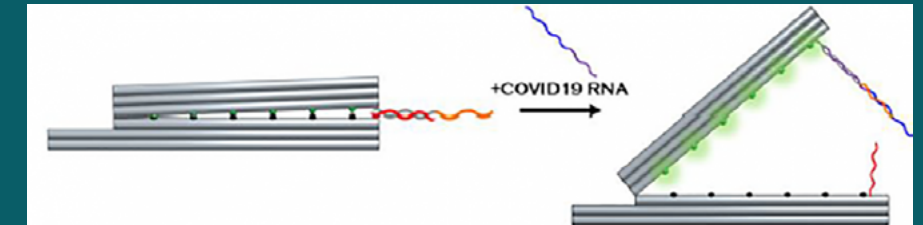
Ohio State team of researchers developing DNA-based rapid diagnostic test for COVID-19

To ensure a safe return to society, quick, reliable testing is required to identify COVID-19, now considered an endemic disease. To meet this need an Ohio State team of researchers led by mechanical and aerospace engineering professor **Carlos Castro** are developing a rapid diagnostic test for COVID-19 using a DNA-based nanotechnology.

The target product is a bio-sensing device in the form of a disposable kit to be used at point-of-care or in clinical labs for the rapid diagnosis of patients with COVID-19, according to **Christopher Lucas**, a research scientist at Ohio State's Nanoengineering and Biodesign Laboratory.

In contrast to current, molecular-based COVID-19 testing, these tests are faster – while retaining accuracy. The disposable tests are also more accessible for underserved areas, and able to be produced for the high-volume testing required to return to normal, everyday activities.

"To date, COVID-19 was confirmed in over 100 million people and caused over 2 million fatalities worldwide," Lucas said. "A rapid and accurate P.O.C. [point of care] diagnostic test for COVID-19 is critical to enable safe re-entry and long-term stability of an open society."



'Hinge' DNA origami biosensor designed to detect and respond to SARS-CoV-2 viral RNA, the virus that causes COVID-19. (Left) COVID-19 Biosensor closed and ready to sense a specific sequence of SARS-CoV-2 viral RNA. (Right) Upon detection, the COVID-19 Biosensor is opened to allow for a detectable fluorescent signal. The COVID-19 Biosensor will lead to development of a rapid molecular COVID-19 diagnostic test.

Researchers envision their diagnostic test being used in a variety of places including clinical settings, government and private buildings, sporting events, concerts, schools, universities and more.

At the beginning of the pandemic, the team was not sure how to face the urgent and complex problem of COVID-19. Quickly, **Patrick Halley**, the research engineer for the team, came up with the idea to develop a SARS-CoV-2-biosensing DNA origami device.

Dr. Carlos Castro, principal investigator at the Nanoengineering and Biodesign Laboratory, was quick to support the researchers' idea. Lucas said that Castro's expertise in nanoengineering offered tremendous direction to their efforts to develop the technology as quickly as possible.

The possibilities of this new test have the potential to go well beyond the current disease that is being faced on a global scale.

"Our COVID-19 biosensing device can be easily changed to detect other viral diseases like the flu and the coronavirus at the same time. Also, the device can be changed to keep up with the mutant variants of the coronavirus very quickly," Lucas said.

Because of the possibility for widespread impact, Lucas and Halley hope to deliver the Ohio State-designed test to the public. The researchers hope to launch a biotech startup company that will allow them to bring their technology to the public much quicker than originally planned.

Read More at go.osu.edu/RI_Testing

Written by Jake Rahe



A quantum step to a heat switch with no moving parts

Researchers have discovered a new electronic property at the frontier between the thermal and quantum sciences in a specially engineered metal alloy – and in the process identified a promising material for future devices that could turn heat on and off with the application of a magnetic “switch.”



Heremans

Under the influence of an external magnetic field, the researchers found, these oddly behaving electrons manipulate heat in ways not seen under normal conditions. On both the hot and cold sides of the material, some of the electrons generate heat, or energy, while others absorb energy, effectively turning the material into an energy pump. The result: a 300% increase in its thermal conductivity.

Take the magnet away, and the mechanism is turned off.

“The generation and absorption form the anomaly,” said study senior author **Joseph Heremans**, professor of mechanical and aerospace engineering and Ohio Eminent Scholar in Nanotechnology at The Ohio State University. “The heat disappears and reappears elsewhere – it is like teleportation. It only happens under very specific circumstances predicted by quantum theory.”

This property, and the simplicity of controlling it with a magnet, makes the material a desirable candidate as a heat switch with no moving parts, similar to a transistor that switches electrical currents or a faucet that switches water, that could cool computers or increase the efficiency of solar-thermal power plants.

“Solid-state heat switches without moving parts are extremely desirable, but they don’t exist,” Heremans said. “This is one of the possible mechanisms that would lead to one.”

The research was published June 7, 2021 in the journal *Nature Materials*.

The bismuth-antimony alloy is among a class of quantum materials called Weyl semimetals – whose electrons don’t behave as expected. They are characterized by properties that include negatively and positively charged particles, electrons and holes, respectively, that behave as “massless” particles. Also part of a group called topological materials, their electrons react as if the material contains internal magnetic fields that enable the establishment of new pathways along which those particles move.

In physics, an anomaly – the electrons’ generation and absorption of heat discovered in this study – refers to certain symmetries that are present in the classical world but are broken in the quantum world, said study co-author **Nandini Trivedi**, professor of physics at Ohio State.

Bismuth alloys and other similar materials also feature classical conduction like most metals, by which vibrating atoms in a crystal lattice and the movement of electrons carry heat. Trivedi described the new pathway along which light-like electrons manipulate heat among

themselves as a highway that seems to appear out of nowhere.

“Imagine if you were living in a small town that had tiny roads, and suddenly there’s a highway that opens up,” she said. “This particular pathway only opens up if you apply a thermal gradient in one direction and a magnetic field in the same direction. So you can easily close the highway by putting the magnetic field in a perpendicular direction.



Trivedi

“No such highways exist in ordinary metals.”

When a metal like copper is heated and electrons flow from the hot end to the cold end, both the heat and the charge move together. Because of the way this highway opens in the experimental Weyl semimetal material, there’s no net charge motion – only energy movement. The absorption of heat by certain electrons represents a break in chirality, or directionality, meaning that it’s possible to pump energy between two particles that wouldn’t be expected to interact – another characteristic of Weyl semimetals.

The theoretical physicists and engineers collaborating on this study predicted that these properties existed in specific bismuth alloys and other topological materials. For these experiments, the scientists constructed the specialized alloy to test their predictions.

“We worked hard to synthesize the correct material, which was designed from the ground up by us to show this effect. It was important to purify it way below the levels of impurities that you find in nature,” Heremans said. As composed, the alloy minimized background conduction so the researchers could detect the behavior of the massless electrons, known as Weyl Fermions.

“In ordinary materials, electrons drag around with them a small magnet. However, the peculiar electronic structure of these bismuth alloys means the electrons drag around a magnet almost 50 times bigger than normal,” said Michael Flatté, professor of physics and astronomy at the University of Iowa and a study co-author. “These huge subatomic magnets allowed the novel electronic state to be formed using laboratory magnetic fields.

“These results show that theories developed for high-energy physics and subatomic particle theories can often be realized in specially designed electronic materials.”

Like everything quantum, Heremans said, “what we observed looks a little like magic, but that is what our equations say it should do and that is what we proved experimentally that it does.”

One catch: The mechanism in this material works only at a low temperature, below minus 100 degrees Fahrenheit. With the fundamentals now understood, the researchers have lots of options as they work toward potential applications.

“Now we know what materials to look for and what purity we need,” Heremans said. “That is how we get from discovery of a physical phenomenon to an engineering material.”

This work was supported by Ohio State’s Center for Emergent Materials, which is a National Science Foundation Materials Research Science and Engineering Center.

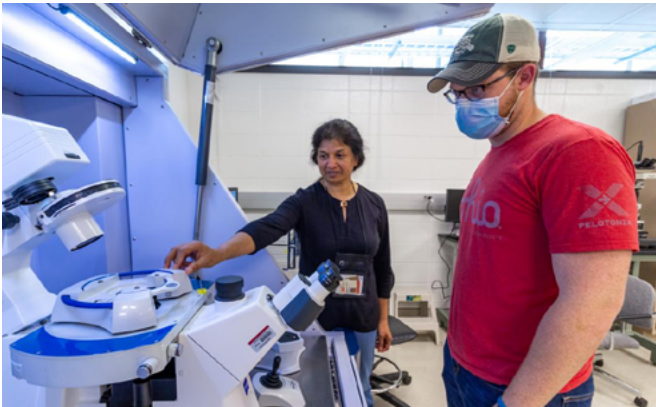
Additional co-authors include Dung Vu and Wenjuan Zhang of Ohio State and Cüneyt Şahin of the University of Iowa. Flatté and Şahin were also affiliated with the University of Chicago at the time this work was done.

See an illustration on page 12

Written by Emily Caldwell, Ohio State News



New shared-use atomic force microscope in Scott Lab enables novel applications in imaging



Agarwal (left) and a student with the AFM in Scott Lab

A newly installed atomic force microscope (AFM) coupled to a fluorescence light microscope is open for shared use in Scott Laboratory.

This multi-user facility is home to a state-of-the-art Bruker Resolve AFM, enabling novel applications in imaging, analyzing and manipulating matter at the nanoscale. Atomic force microscopy enables the imaging and nano-mechanical analysis of most types of surfaces, including polymers, ceramics, and biological samples.

“The nanoscale and molecular-level insights that can be provided by AFM are expected to generate new research directions for basic and translational biomedical research as well as in nanotechnology and polymer science,” said **Gunjan Agarwal**, professor in Mechanical and Aerospace Engineering (MAE) who leads the lab. “This AFM can analyze samples in a liquid environment at the nanoscale level, which cannot be achieved by other existing AFMs on campus or by electron microscopy.”

The microscope was acquired via a National Institutes of Health (NIH) S10 award, led by Agarwal. This is the second S10 award led by Agarwal, who had previously

established and directed another Bio-AFM facility in the Davis Heart and Lung Institute, in 2006.

The AFM laboratory as a university-wide shared resource will enable collaborations across various departments and colleges, as can already be witnessed in some of the user projects.

The Institute for Materials Research (IMR) is set to provide the lab further support through its first five years of operation. Along with IMR, the Office of Research, departments of MAE and Biomedical Engineering, and the colleges of Engineering, Arts and Sciences, and Pharmacy have committed funds to support this facility.

The new AFM is the only shared AFM on campus capable of imaging in fluid, making it an invaluable resource for biomedical research.

“In biological samples, it is really important that we can keep the samples hydrated (e.g. live or fixed cells, tissues and even biomolecules) and in their desired conditions,” Agarwal said. “The instrument is very bio-friendly.”

Additionally, the instrument’s AFM module sits above a light microscope, allowing the coupling of fluorescence and AFM images from the same region. In the examination of bio samples, fluorescent signals will allow users to perform AFM analysis of specific regions of interest identified in fluorescence images.

Finally, the new AFM is equipped with state-of-the art features like the PeakForce Tapping mode, Quantitative Nano mechanics, and even Kelvin Probe Microscopy.

Agarwal has also developed and offers a new course “Microscopy in Biomechanics” that discusses the fundamental principles of light microscopy and AFM in imaging and nanoscale mechanical analysis.

Written by Mike Huson

The cones in this image illustrate the equations of motion of electrons when an external magnetic field is applied to the bismuth alloy engineered for the study. Green lines and purple lines represent electrons that generate and absorb energy, respectively. Read more (page 11)

Illustration by Renee Ripley





Ohio State students receive Department of Energy awards

Two Ohio State engineering students recently received accolades from the U.S. Department of Energy's Nuclear Engineering University Program (NEUP). The Department of Energy's Office of Nuclear Energy announced awards of around \$5 million, which provides 50 scholarships and 31 fellowships at 35 institutions across 23 states. Ohio State is one of these institutions, and received one scholarship and one fellowship.



Nick Krammer, an undergraduate chemical engineering student was the recipient of an NEUP undergraduate scholarship. Krammer began working as a student assistant for the Ohio Emergency Management Agency's Radiological Division in the fall of 2020. His work involved calibrating dosimeters and decommissioning obsolete Geiger Counters. Over winter break, Krammer was able to gain experience at Ohio State's Nuclear Reactor Lab before joining the Nuclear Analysis and Radiation Sensor Lab (NARS) run by Dr. **Raymond Cao**.

The scholarship will allow Krammer to dedicate his time to nuclear research during his final undergraduate semester. He hopes it will also help provide more opportunities to explore the nuclear research and engineering field.

"I'd encourage other students who are interested in a particular field outside from their direct major to pursue a [nuclear engineering] minor," Krammer said. "Pursuing the minor opened doors for many opportunities I otherwise would not have had."

The NEUP fellowship recipient was nuclear engineering graduate student, **Pearle Lipinski**. Lipinski is the first dual nuclear and law student, and recently received the Marie

Sklodowska-Curie Fellowship from the International Atomic Energy Agency.

Lipinski is interested in researching how advanced models of probabilistic risk assessment (PRA) can be adapted as advanced nuclear reactors (ANR) mature and become part of the U.S. energy infrastructure.

"In particular, I plan to look at how a specific form of advanced PRA known as Dynamic PRA, which uses simulation to predict risk scenarios instead of deterministic models, could be verified and validated as part of its possible use in regulating ANRs," said Lipinski.

As a law student, Lipinski had the opportunity to work with the Department of Energy's Office of the General Counsel for Civilian Nuclear Programs this past semester.

"It was exciting to be in that office right after the passing of the bipartisan Energy Act of 2020, which provides for significant development of nuclear energy technologies within the coming decades," Lipinski said. "I'm honored to be supported by DOE as part of these efforts at this unique time in US nuclear energy development."

The NEUP fellowship provides funding to assist with tuition and living expenses for three years. It also provides the opportunity for fellows to work as paid interns at DOE sites.

Lipinski said her dual degree program was an intentional way to intersect her legal and engineering interests, and to push forward on U.S. nuclear energy. She hopes that by the end of her fellowship, her work will have contributed to a cleaner U.S. energy infrastructure.



ASSURE program lands aerospace researchers FAA grants

The Federal Aviation Administration (FAA) announced that \$5.8 million would be going toward research, education and training grants to universities involved in the FAA's Alliance for System Safety of UAS (Unmanned Aircraft Systems) through Research Excellence, or ASSURE program.



McCrink

Research scientist at the Aerospace Research Center, **Matt McCrink** said the goal of ASSURE is to assist the FAA by studying the technology and logistics behind unmanned flight.

"The ASSURE program in general is setup to essentially facilitate and investigate all of the key technologies that are going to be required and policies that will be necessary to integrate unmanned systems into the national air space," said McCrink. "We look at what we have to do to safely operate a whole number of autonomous vehicles in close proximity to existing manned air traffic, and utilize the same air space and infrastructure to do that."

Ohio State is one of the 24 research institutes that make up the ASSURE program, and has been for the last six years. Recently, ASSURE-based grants and research at Ohio State have ranged from airplane sensors, to injury assessment.

"We have a large level of diversity which we can use to answer a lot of these questions, be they policy, technical, or experimental work. We have the right people to do that," said McCrink.

And Ohio State research are doing just that. In the latest round of ASSURE grants, Ohio State was awarded grants in three of the eight FAA research areas: air carrier operations, UAS cargo operations and high-bypass UAS engine ingestion test.

Mechanical and aerospace engineering professor **Kiran D'Souza** is one of the researchers looking into high-bypass UAS engine ingestion. D'Souza was involved with a similar FAA study that recently found drones to be more damaging than birds of the same weight when ingested by aircraft engines.



D'Souza

D'Souza is leading an effort to develop a fan model that can recreate the structural and vibratory features of a modern high-bypass ratio fan. He is also coordinating with research partners to conduct high-speed impacts of UASs and UAS components against an angled titanium plate to validate an existing UAS quadcopter model.

The researchers will then do a series of ingestion studies with the validated UAS model and high-bypass ratio fan model. These simulations will give researchers a better understanding of what an ingestion of a UAS by a high-bypass engine would look like.

"The work will seek to define best practices for these ingestion studies and will provide an open source fan model for use in further studies," said D'Souza.

The two other FAA grants are led by McCrink. The research being done in air carrier operation revolves around the urban air mobility space, a field that has seen growing interest in the last few years. McCrink considers this to be a next-generation project.

"The idea is very much like the Jetsons," said McCrink, "you call up your personal air taxi and it comes and picks you up, and takes you from A to B."

"This really is laying the groundwork for the next step, where the public will be able to utilize autonomous transportation," said McCrink.

Read more at go.osu.edu/RI_ASSURE

FACULTY RECOGNITION

Castro earns prestigious bioengineering honor



Carlos Castro, associate professor of mechanical and aerospace engineering, was elected this week into The American Institute for Medical and Biological Engineering (AIMBE) College of Fellows.

As an AIMBE Fellow, Castro joins 2,000 outstanding bioengineers, entrepreneurs and innovators who have distinguished themselves through significant and transformative contributions in research, education and industrial practice. Fellows represent the top two percent of the medical and biological engineering community in the country.

Director of the Nanoengineering and Biodesign Lab, Castro was nominated, reviewed and elected by peers and members of the College of Fellows for outstanding contributions to the development of DNA nanotechnology for biophysics, bioengineering, and biomedical applications.

AIMBE Fellows are among the

most distinguished medical and biological engineers including 3 Nobel Prize laureates, 18 Fellows having received the Presidential Medal of Science and/or Technology and Innovation, and 195 also inducted to the National Academy of Engineering, 94 inducted to the National Academy of Medicine and 43 inducted to the National Academy of Sciences.

Giorgio Rizzoni recognized with College of Engineering Faculty Mentoring Award



Center for Automotive Research (CAR) Director, **Giorgio Rizzoni** who has been awarded the Faculty Mentoring Award by The Ohio State University College of Engineering. The award recognizes Professor Rizzoni's role as a mentor to young and new faculty in the areas of teaching, research, advising students, industrial collaborations, seeking funding and professional growth.

Throughout his 31 years at Ohio State as Director of CAR and Professor in the Departments of Mechanical and Aerospace (MAE) and Electrical and Computer

Engineering (ECE), Rizzoni has mentored some 20 faculty members across multiple academic departments and two colleges.

According to his award nomination, Rizzoni's mentorship has led his mentees to be better educators, better scholars/researchers and better members of the academic community at The Ohio State University as they continue to progress in their careers under his guidance.

Assistant Professor, Jung-Hyun Kim Recognized with Lumley Research Award

Jung-Hyun Kim, assistant professor in the Department of Mechanical and Aerospace Engineering (MAE) was awarded the College of Engineering's Lumley Research Award for his work focusing on energy storage materials and systems to support global transition towards renewable energy.

This award is presented annually and recognizes faculty who have demonstrated significant research contributions and productivity over the last five years.



According to his award nomination, Kim's research has also had a broad impact on STEM education through various high school and college outreach initiatives he has participated in.

Dupaix presented Alumni Award for Distinguished Teaching



Rebecca Dupaix, professor and associate chair for undergraduate programs in the department of mechanical and aerospace engineering, was presented with The Ohio State University's 2020 Alumni Award for Distinguished Teaching. Professor Dupaix has been teaching at Ohio State since the fall of 2003. She teaches courses on statics, mechanics of materials, applied finite element analysis, and continuum mechanics. Her research focuses on the mechanical behavior of polymers and soft biological tissues.

This teaching award comes during an unprecedented year for educators. The pandemic-era challenges, and transition to online and hybrid courses has posed difficulties for students and instructors alike. However, overcoming challenges is something Dupaix said has always been a part of her journey.

Recipients of the Alumni Award

for Distinguished Teaching are nominated by present and former students and colleagues and are chosen by a committee of alumni, students, and faculty. They receive a cash award of \$5000, made possible by contributions from the Alumni Association, friends of Ohio State, and the Office of Academic Affairs. The recipients will be inducted into the university's Academy of Teaching, which provides leadership for the improvement of teaching at Ohio State.

Benzakein named Royal Aeronautical Society honorary fellow

Professor of mechanical and aerospace engineering, **Meyer Benzakein**, received an honorary fellowship from the Royal Aeronautical Society. According to the society, an honorary fellowship is "the world's highest distinction for aerospace achievement, awarded for only the most outstanding contributions to the aerospace profession."

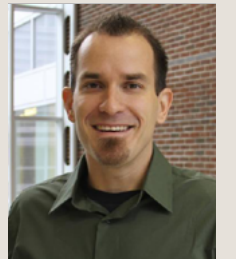
Honorary fellowships are conferred for individuals whose impacts have distinguished them as eminent and influential aerospace engineers. The award is decided by the Royal Aeronautical Society's medals and awards committee, in conjunction with an International Adjudication Panel.

Among his many projects, Benzakein led the design and certification of the CFM56 engine that is used in Boeing aircrafts, and is considered one of the most popular and reliable engines in commercial service.

Benzakein has also been the recipient of the General Electric Chairman's Award for Technology Leadership, an Honorary Doctorate from the University of Poitiers, France, and the Gold Medal of Honor from the Royal Aeronautical Society.

Sutton receives Department of Energy grant for fuel research

Mechanical and aerospace engineering professor, **Jeffrey Sutton**, received a federal research grant from the U.S. Department of Energy's Office of Fossil Energy.



Sutton's project, "Hydrogen Fuel Effects on Stability and Operation of Lean-Premixed and Staged Gas Turbine Combustors," is a collaborative project between The Ohio State University, the University of Michigan and G.E. Power.

The grant comes as part of University Turbines Systems Research (UTSR) program, which focuses on the basic science, questions, and challenges that limit efficient use of gas turbines fuel with pure hydrogen, hydrogen-

natural gas mixtures, or other carbon-free hydrogen-containing fuels.

Agarwal receives NSF grant for work in Nanomaterials and Bioengineering



Dr. Gunjan Agarwal, a professor of mechanical and aerospace engineering, has received a three-year collaborative research grant for \$390,433, from the National Science Foundation (NSF) for her work in Nanomaterials and Bioengineering.

Agarwal's project, "Collaborative research: Magnetic mapping of bio-inspired clusters of iron oxide nanoparticles" is funded by the NSF's Nanoscale Interactions program. The proposed research seeks to understand the fate of and better characterize iron-oxide nanoparticles in biological systems, she said. Agarwal (as lead PI) will be collaborating with Dr. Sam Oberdick, at the National Institute of Standards and Technology (NIST) and the University of Colorado, Boulder, CO, on this project.

Iron oxide nanoparticles have widespread importance for labeling cells and molecules both inside and outside the human body. However, nanoparticles often cluster together in complex bio-environments, and the effect of clustering on their collective magnetic properties is not well understood. So, the

overall objective of this work is to explore the relationship between nanoparticle clustering and resultant magnetic properties.

The grant will be used to support and train graduate and undergraduate students in specialized techniques involving atomic force microscopy and electron microscopy, as well as cell-culture, histology and other analytical techniques. Another outcome of this award will be to develop outreach activities to educate underprivileged students at a local high school about nanoscience and engineering concepts.

Stockar receives NSF Faculty Early Career Development (CAREER) Award



Stephanie Stockar, an assistant professor of mechanical and aerospace engineering, has received a Faculty Early Career Development (CAREER) Award from the National Science Foundation (NSF).

Professor Stockar's award, titled "CAREER: Constrained Optimal Control of Partial Differential Equations for Improving Energy Utilization in Transportation and in the Built Environment," focuses on creating a new mathematical framework to solve optimal control problems in systems described by Partial Differential Equations.

Stockar's research focuses on the application of optimization and optimal control theory to automotive and energy systems. This award will help her establish an emerging and interdisciplinary research program at Ohio State that will explore challenges related to energy optimization and control of transportation networks, district heating networks, and connected and autonomous vehicles.

Through the CAREER program, Stockar will be creating an initiative for sophomore and junior students in the department of mechanical and aerospace engineering, to give them exposure and experience within a research lab.

Soghrati receives federal grants for model-based research



Ohio State professor **Soheil Soghrati** recently received two federal grants for his research totaling \$1 million. Soghrati is an associate professor

of Mechanical and Aerospace Engineering with a joint appointment in the Department of Materials Science and Engineering. He is the director of Automated Computational Mechanics Laboratory (ACML), where he and his research team focus on developing novel computational techniques and artificial intelligence

(AI) algorithms for modeling synthetic and biomaterials.

Soghrati's first grant comes from the Air Force Office of Scientific Research (AFOSR) for his work titled, "Mesh generation and AI-enhanced algorithms for modeling complex materials systems." The goals of this project will be to allow a parallel mesh generation algorithm named CISAMR the ability for automated modeling of 3D crack growth problems. The research also aims to develop a cost-efficient, deep learning based framework to simulate mechanical behaviors of massive structures with complex microstructures.

The second grant Soghrati received is on a collaborative project with North Carolina State University (NCSSU). The project, "Optimization of self-healing fiber reinforced polymer composites via convolutional neural networks," received funding from the Strategic Environmental Research and Development Program (SERDP), a Department of Defense (DoD) sub-program.

"The project provides a perfect collaborative environment between an experimental research team (NCSSU) and a computational research group (ACML) to achieve ambitious objectives of this project," Soghrati said.

The research project aims to develop a sustainable self-healing composite system capable of complete restoration in interlaminar fracture resistance, without compromising mechanical properties.

Bharat Bhushan receives 2020 Tribology Gold Medal



MAE Professor Emeritus **Bharat Bhushan** has been awarded the Tribology Gold Medal Award by the International Tribology Council (ITC), for lifetime outstanding and supreme achievements in the field of tribology.

The award is in recognition of his outstanding contribution to Tribology, with five decades of distinguished and continued contributions to the advancement of the field. His research contributions have significantly extended to the interdisciplinary areas of biological and materials science and he has pioneered the tribology of magnetic storage devices, bio-/nanotechnology, cosmetics and biomimetics, nanotribology, and green tribology

Professor Bhushan was born in a small town, Jhinhana, India. He received his B.S. in Mechanical Engineering from the Birla Institute of Technology & Science. At the age of twenty, Bhushan left India to pursue an advanced degree in Tribology at Massachusetts Institute of Technology. He took the first course in Tribology from Professor Ernest Rabinowicz, who was the 1998 Gold Medal winner and a student of the pioneer, Professor David Tabor, the first Gold Medal winner in 1972. He

received his M.S. in Mechanical Engineering from MIT, followed by an M.S. in Mechanics and a Ph.D. in Mechanical Engineering from the University of Colorado at Boulder, and an MBA from Rensselaer Polytechnic Institute.

MAE Professor Mazumder co-authors new textbook



The fourth edition of a book co-authored by Professor of Mechanical and Aerospace Engineering, **Sandip Mazumder**, will soon be published by Academic Press (Elsevier). The textbook, titled Radiative Heat Transfer, covers all aspects of thermal radiation including fundamental aspects of radiation, radiative properties of solids, liquids, and gases, and all methods of solving the radiative transfer equation in multidimensional media. The 926-page book is divided into 24 chapters. The major additions to the fourth edition are large sections on climate change and global warming and emphasis on practical applications, Mazumder said.

The book will be released both in print format (as a hardcover textbook) and in electronic format in August, and can be used in graduate level courses such as ME 6510 and ME 7510.

STUDENT RECOGNITION

Dung Vu selected for Ohio State Presidential Fellowship



Ohio State mechanical engineering PhD student **Dung Vu** was selected as one of this year's recipients of the Ohio State Presidential Fellowship.

The fellowship is given to students who "embody the highest standards of scholarship" in the graduate programs at the university going into the last stages of their dissertation research or terminal degree project. Recipients are given a monthly stipend for living expenses so they can focus solely on completing their research, as well as help with travel expenses to present at national conferences.

Vu's research explores new mechanisms of energy transport by electrons based on topological properties of their equations of motion. This work not only advances fundamental understandings of electrons in solid, but also provides blueprints for future devices such as dissipation-less electronics and solid-state thermal transistors.

He is advised by Professor Joseph Heremans, and works in Heremans'

Thermal Materials Lab in Scott Lab.

"I am blessed to work under advisement of Prof. Heremans," Vu said. "He is not only among the top scholar in his field but also a great character both inside and outside the lab. Prof. Heremans always make sure that he dedicates enough time and effort in advising his students. He also gives us guidance in navigating our career whether we want to work in industry or academia since he had extensive experience in both. Overall, I am very satisfied with our lab."

go.osu.edu/RI_Vu

Lipinski receives IAEA Marie Skłodowska-Curie Fellowship



Nuclear engineering student Pearl Lipinski received a Marie Skłodowska-Curie Fellowship from the International Atomic Energy

Agency (IAEA). According to the IAEA, more than 550 candidates from over 90 countries were submitted to the fellowship program for consideration. The fellowship is geared towards increasing female participation in nuclear science, and provides scholarships to 100

graduate students studying nuclear-related subjects.

Lipinski is advised by Dr. Carol Smidts, and is in her first semester as an MAE graduate student. As a dual nuclear engineering and law student, Lipinski hopes to combine her interests in regulatory law with the field of nuclear engineering.

The fellowship provides students with stipends for tuition and living expenses. It also allows Lipinski the opportunity to pursue an internship at the IAEA in Vienna, Austria.

"To be a part of the inaugural class is particularly humbling. I know that Professor Smidts' career has also been inspired by that of Skłodowska-Curie, and it is uniquely special to have this fellowship support her academic legacy as well," Lipinski said.

go.osu.edu/RI_Lipinski

PhD student receives ASME best paper award

Deb Banerjee, a PhD Candidate in the department of mechanical and aerospace engineering, was recently awarded the Fluid Measurement & Instrumentation Technical Committee Best Paper Award at the 2020 American Society of Mechanical Engineers (ASME) International Mechanical Engineering Congress and



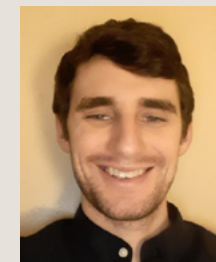
Exposition (IMECE). Banerjee is advised by MAE professor Dr. Ahmet Selamet.

The paper, titled "Particle Image Velocimetry as Applied to Inlet Flow Field of a Turbocharger Compressor at Varying Rotational Speeds with Emphasis on Surge," explores surge instabilities at the inlet of a turbocharger compressor at different rotational speeds using Particle Image Velocimetry – a laser diagnostic technique.

Banerjee said the work describes detailed characterization of the instabilities, leading to improvements in the fundamental understanding of the involved physical processes. The data acquired by the team will help validation of computational fluid dynamics predictions of the turbocharger flow field.

Since receiving the award, the paper has also been accepted to appear in the ASME Journal of Fluids Engineering.

MAE PhD student wins AIAA best international student paper



Aerospace engineering graduate student, **Spencer Stahl**, won first place in the masters category of the international student paper competition at the American Institute of

Aeronautics and Astronautics (AIAA) Scitech conference.

Stahl presented his paper titled "Effects of Fountain Flow Interaction on Dual Jet Impingement at Mixed Operating Conditions" virtually at the January 2021 conference. The focus of his paper explores the challenges of Vertical Take-Off and Landing (VTOL) aircraft, and is supported by the Office of Naval Research (ONR).

"Our interest is in understanding the hot turbulent flow generated underneath the aircraft that creates difficult conditions for stability, control, and propulsion systems for the aircraft," said Stahl.

His work also investigates the aero-acoustic feedback mechanisms that create high levels of sound that can be damaging to nearby flight deck personnel. Stahl said that a successful model of obscured jet dynamics would give engineers new insights to help combat this problem.

Stahl's research is done at the High Fidelity Computational Multi-Physics Lab (HFCMPL) led by MAE professor Datta Gaitonde. Stahl's other research interests include developing the next generation of analysis techniques for computational fluid dynamics.

Two MAE PhD students honored as Ohio State Presidential Fellows

Ohio State mechanical engineering PhD student **Ali Asghari Adib** and aerospace engineering PhD student

Troy Shilt were selected as two of this year's recipients of the Ohio State Presidential Fellowship.

The fellowship is given to students who "embody the highest standards of scholarship" in the graduate programs at the university going into the last stages of their dissertation research or terminal degree project. Recipients are given a monthly stipend for living expenses so they can focus solely on completing their research, as well as help with travel expenses to present at national conferences.



Asghari Adib

Asghari Adib is advised by Dr. David Hoelzle and is a doctoral candidate who came to Ohio State from Tehran, Iran.

Asghari Adib's research focuses on developing a novel endoscopic additive manufacturing tool to 3D print biomaterials inside the patient body, in a minimally invasive manner.

He joined Hoelzle Research Lab at OSU in 2017 as a PhD student, in order to pursue his lifetime dream of making an impact at the confluence of science and engineering.

Troy Shilt is advised by Dr. Jack McNamara and is a doctoral candidate who came to Ohio State from Dayton OH. Shilt's research focuses on



Shilt

developing novel numerical solutions to long standing fluid dynamic problems using the generalized finite element method. This approach

allows the implementation of a priori knowledge using enrichment functions. A focal point of the research is determining enrichments which are well-suited for fluid dynamic problems.

Professor and PhD student receive AFRL/DAGSI student-faculty fellowship

Mechanical and Aerospace Engineering graduate Student, **TJ Miller**, and his advisor, Dr. **Jack McNamara**, have been selected for the 2021 Air Force Research Laboratory – Defense Associated Graduate Student Innovators (AFRL/DAGSI) Ohio Student-Faculty Fellowship program. They were selected for their coauthored proposal titled “Temporal Convergence and Stability Assessment of the Generalized Finite Element Method (GFEM) for Multi-scale Field Problems.”

Miller said their research looks specifically at transient heat transfer problems with highly localized loading conditions. The team aims to demonstrate how to most efficiently time march numerical solution of differential equations when using GFEM.

“The end goal is to extend this to approximating the extreme environments in high-speed flow problems accurately at reduced computational cost,” said Miller.

This year, 52 proposals were submitted to the fellowship program. From that pool, only 13 were selected for funding.

McNamara said he is confident in Miller’s work after having advised him previously during his time as an undergraduate researcher. The funding will also allow Miller to begin to make progress on his PhD work, while maintaining ties with the Air Force Research Laboratory at Wright-Patterson Air Force Base.

Audrey Blizard, set to receive a 2021 NSF GRFP Fellowship

Audrey Blizard

An Ohio State mechanical engineering student has been notified that she will receive a 2021 National Science Foundation (NSF) Graduate Research Fellowship Program (GRFP) Fellowship.



Audrey Blizard, a graduate student at Ohio State, works under the supervision of Professor Stephanie Stockar. Blizard completed her undergraduate studies at Penn State University before coming to Ohio State for her doctorate.

Selection for the honor is based on

a graduate student’s abilities and accomplishments, as well as their potential to contribute to the vitality of US science and engineering enterprises, according to the NSF GRFP website. The GRFP has a long history of selecting recipients who achieve high levels of success in their future academic and professional careers.

Blizard’s current research is focusing on the modeling, optimization, and control of district heating networks (DHNs). DHNs provide heated water through a network of underground pipes to buildings to heat them.

Ohio State MAE student GNC finalist at SciTech 21

An Ohio State mechanical engineering student from the Laboratory for Autonomy in Data-Driven and Complex Systems is a finalist for the Guidance, Navigation and Control (GNC) Graduate paper competition at the 2021 American Institute of Aeronautics and Astronautics SciTech Forum and Exposition.

Rachit Aggarwal, PhD Candidate and Graduate Research Associate at

Laboratory for Autonomy in Data-Driven and Complex Systems (LADDCS), has been chosen as one of six finalists out of 225 submissions for his paper titled, “Multi-UAV Path Planning in a Spreading Wildfire”. Aggarwal



is advised by Dr. Mrinal Kumar, Director at LADDCS.

GNC is the only discipline within SciTech that requires a full paper on completed research for review and sets a high bar for selecting its best papers. Aggarwal received a \$500 award for being a finalist, and free registration for Scitech’21.

“I feel excited to be recognized by American Institute of the Aeronautics and Astronautics (AIAA), the world’s largest professional society for aerospace,” he said. “I wouldn’t able have been able to accomplish this without the support of my advisor, Dr. Kumar, and my wonderful colleagues in the research group. This recognition has encouraged me to keep up the hard work.”

The paper focuses on estimating the spread of wildfires in real time and developing a mission plan for multiple drones to capture aerial images while avoiding dangers to operational safety. The overall objective of the research is to optimize the mission in such a way that drones expend minimum energy to travel and maximizes the number of regions that are scanned by multiple UAVs as opposed to a single UAV.

MAE graduate students win AIAA best paper awards

Two mechanical and aerospace engineering graduate students recently received best student paper awards from the American Institute of Aeronautics and

Astronautics (AIAA). **Keegan Orr** received the 2020 Walter Lempert Best Student Paper Award from the AIAA Aerodynamic Measurement Technology Technical Committee. **Elijah Jans** received the 2020 Best Student Paper Award from the AIAA Plasmadynamics and Lasers Technical Committee.

Both Keegan and Elijah are pursuing their PhD at the Nonequilibrium Thermodynamics Laboratories (NETL) as National Defense Science and Engineering (NDSEG) Fellows.



Orr

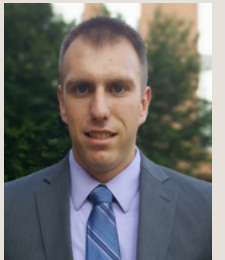
Orr’s award is named after Professor Walter Lempert, a former faculty member at the department of mechanical and aerospace engineering at The Ohio State

University. Lempert was scientist and engineer who had a well-known impact on the development of laser diagnostics of high-speed reacting flows and low-temperature plasmas. The AIAA Aerodynamic Measurement Technology technical committee established their student paper competition in his honor, to recognize the students’ accomplishments in development of new optical diagnostics in fluid mechanics, plasma physics, and energy transfer.

Orr’s paper focused on the development and applications of a new laser diagnostic technique known as Electric Field Induced

Second Harmonic (EFISH) generation. This technique is based on the effect that occurs when an electric field is applied to an otherwise isotropic medium, typically a gas or liquid. A dipole moment is induced in the medium. The induced dipole moment allows the medium to undergo the nonlinear optical process of second harmonic generation. Intense laser light produces coherent second harmonic signal proportional to the square of the applied electric field in the medium, facilitating high temporal and spatial resolution electric field measurements.

Jans’ received his best student paper award from the Plasmadynamics and Lasers Technical Committee. His research is based on using laser diagnostics for measurements of key parameters of electric discharge plasmas and hypersonic flows.



Jans

Jans’ paper outlines the development and implementation of an ultra-sensitive laser absorption technique to measure the concentration of a metastable, or “dark”, excited state of nitrogen molecules controlling intense ultraviolet radiation in nonequilibrium hypersonic air flows, such as created behind strong shock waves. This is the first time when this technique was used in a supersonic wind tunnel.

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*Aerospace graduate student Kali Boyd cuts new wings for her reverse-engineered
UAV model from their mold. Read more: page 7*