AEROGRAM

FALL 2021

PURDUE UNIVERSITY SCHOOL OF AERONAUTICS AND ASTRONAUTICS

UAS Research and Test Facility Takes Flight

Hangar 4 now home to world's largest indoor motion capture system

CRADLE EXPANDS

BANDLA JOINS EXCLUSIVE GROUP WITH JULY FLIGHT

Sirisha Bandla couldn't quite articulate the experience.

She wanted something better than "incredible" to describe the suborbital flight to space on Virgin Galactic's VSS Unity on July 11, but that's ultimately what settled in her mind soon after realizing a dream she'd held since childhood.

And another she probably hadn't quite articulated.

Bandla not only became a commercial astronaut with the flight, reaching 53.5 miles above the Earth, but she also officially was anointed into Purdue University's Cradle of Astronauts. Bandla (BSAAE '11) is the 26th member of the Cradle and 17th AAE alum.

"Seeing the view of Earth is life-changing," Bandla told NBC News after the flight. "But also the boost, the rocket motor kicking in. The whole trip to space and back has just been amazing."

Bandla, the company's vice president for government affairs and research operations, was one of four mission specialists on the flight, the first fully crewed for Virgin Galactic. Her role was to evaluate the researcher experience.

Bandla is only the second commercial astronaut in the Cradle. The first also was on VSS Unity. Beth Moses, the company's Chief Astronaut Instructor, served as cabin lead and test director in space, overseeing the safe and efficient execution of the test flight objectives.

"Truly phenomenal the second time," Moses (BSAAE '92, MSAAE '94) said in the post-flight press conference.

Like Moses before her, Bandla made sure to honor her alma mater on her historic flight.

Tucked inside the inner pocket of Bandla's spacesuit was a small pennant, which she later gifted to the School. When asked in the press conference after the flight that she took to space, Bandla shared the news and then followed with "Boiler up!" To which Moses chimed in, "Go Boilers!"

AEROGRAM
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PURDUE UNIVERSITY®
School of Aeronautics and Astronautics

Alumna Sirisha Bandla was a mission specialist on Virgin Galactic's July 2021 suborbital flight, making her the second commercial astronaut in Purdue University's Cradle of Astronauts.

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ON THE COVER: Managing Director James Goppert (left) and AAE Professor Inseok Hwang stand in the Purdue UAS Research and Test Facility (PURT), which boasts the largest indoor motion capture system in the world. (Rebecca McElhoe)

IN THIS ISSUE:

LETTER FROM THE HEAD

JOHN UNDERWOOD

WILLIAM CROSSLEY
J. WILLIAM UHRIG AND ANASTASIA VOURNAS HEAD OF AERONAUTICS AND ASTRONAUTICS

Thank you for reading this year's issue of the *Aerogram*. We are again offering this primarily as a digitally based publication that allows for additional links and dynamic content. We think this is a nice complement to our healthy social media presence and regular postings of news items and announcements on our website. There are several articles here about research underway in the School and a few articles featuring work some of our alumni are pursuing. We've again organized these stories to show how the work in the School of Aeronautics and Astronautics aligns with our four themes: safe, efficient and sustainable air transportation; access to and exploration of space; maintaining defense and security; and using aerospace to facilitate new opportunities. We hope these stories convey the commitment and excellence the people of AAE bring to these activities.

We are adding three new faculty members to aeronautics and astronautics during the 2021-22 academic year. In August, Professor Leifur Leifsson joined us in our aerospace systems area after several years as a faculty member at Iowa State. Professor David Arnas also joined AAE in August as part of our astrodynamics and space applications area; he has previous teaching experience in Spain and recently completed a post-doctoral position at MIT. In January 2022, after completing a post-doctoral position with NASA's Jet Propulsion Lab, Professor Kenshiro Oguri also will join us as part of the astrodynamics and space applications area. At the end of last academic year, Professor John Sullivan retired after a productive Purdue career, including a term as head; we will miss John's contributions. During 2021-22, we also will be searching for additional faculty members to extend and enhance the research we conduct in the School and to assist with our educational mission.

The growth in AAE continues with another student enrollment record. We now have 1,077 undergraduate students and 603 graduate students. Just 10 years ago, we had 546 undergraduate and 369 graduate students. Even with this growth, we are maintaining our strong reputation; we have returned to fourth in the 2022 *U.S. News and World Report* rankings for undergraduate aerospace engineering programs.

We began this academic year with the coronavirus pandemic still present. Our research continued through the pandemic with protocols and operating procedures to keep everyone safe and healthy. Classrooms are back to full density this year, while students, staff and faculty are wearing masks inside buildings as an additional layer of protection. Via Purdue's self-reporting system, 80 percent of students, 75 percent of staff and 90 percent of faculty were vaccinated as of early September. We are hosting visitors on campus, and in-person events restarted in September with the Charles Rolls and Henry Royce Memorial Lecture.

Thanks to all of you for your continuing interest in and support of what we do in the School of Aeronautics and Astronautics. As we make our way through this academic year facing some continuing challenges from the pandemic and adjusting to our increasing enrollment, we value the numerous ways you interact with us. When you are ready to visit, we are looking forward to welcoming you back to campus.

AERONAUTICS AND ASTRONAUTICS BY THE

NUMBERS

RANKED **4TH**

BEST UNDERGRADUATE AEROSPACE/ AERONAUTICAL/ ASTRONAUTICAL ENGINEERING

U.S. News and World Report (2022)

RANKED **6TH**

BEST GRADUATE AEROSPACE/ AERONAUTICAL/ ASTRONAUTICAL ENGINEERING

U.S. News and World Report (2022)

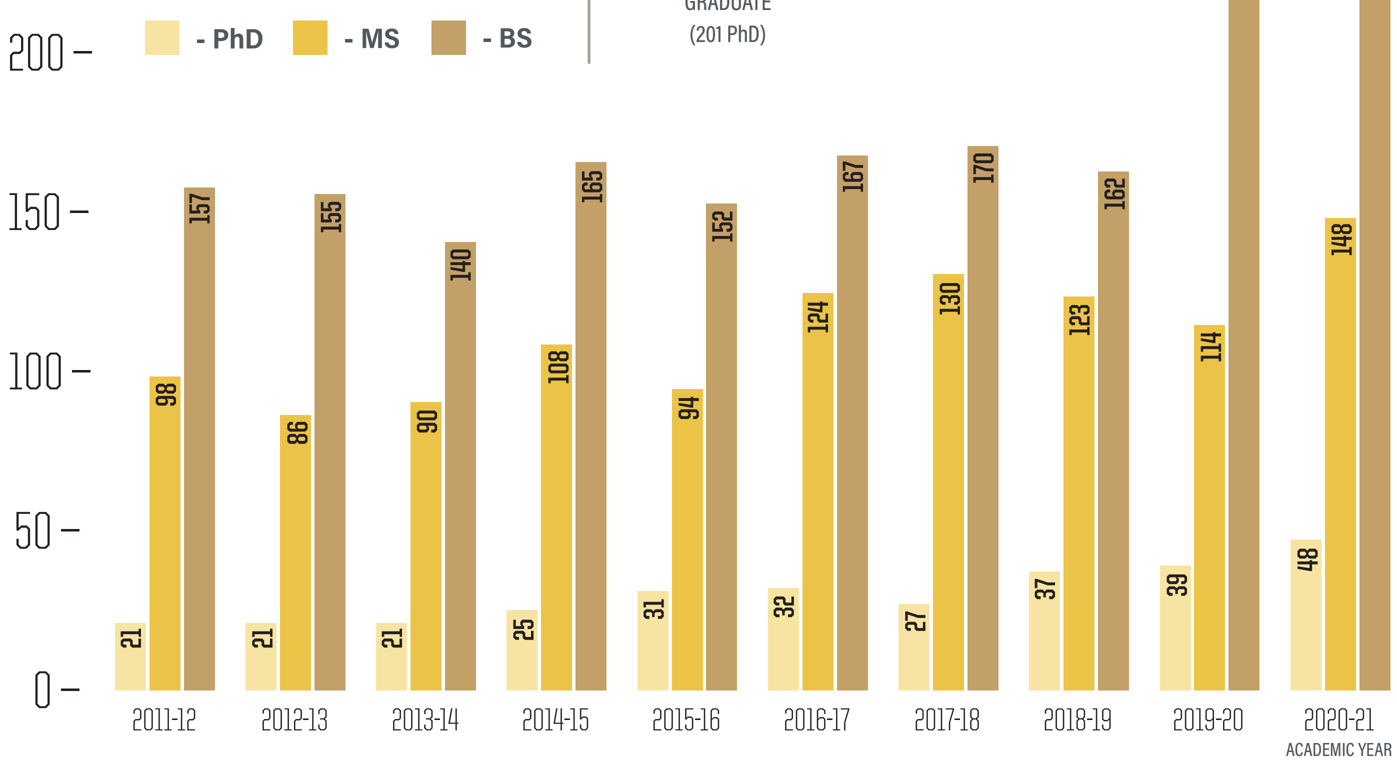
THE FACULTY (FALL 2021)

40	TENURED/TENURE-TRACK FACULTY
28	FULL PROFESSORS
08	ASSOCIATE PROFESSORS
04	ASSISTANT PROFESSORS
02	LECTURERS
01	RESEARCH FACULTY
05	VISITING FACULTY
13	COURTESY FACULTY

THE STUDENTS (2021 FALL ENROLLMENT)

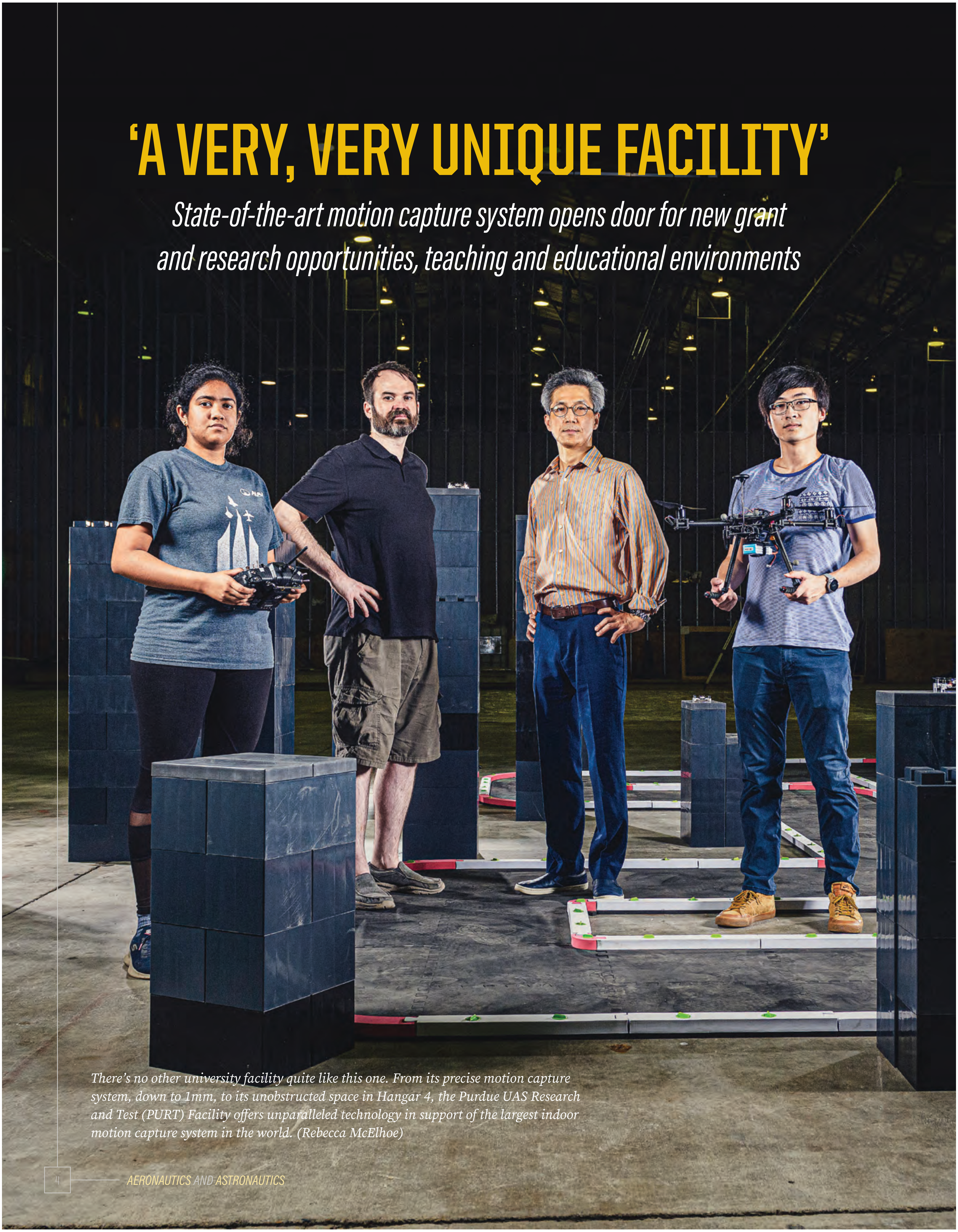
1077	UNDERGRADUATE	17% FEMALE	8% URM	12% INTERNATIONAL
603	GRADUATE (201 PhD)	17% FEMALE	8% URM	29% INTERNATIONAL

LAST DECADE: GRADUATES

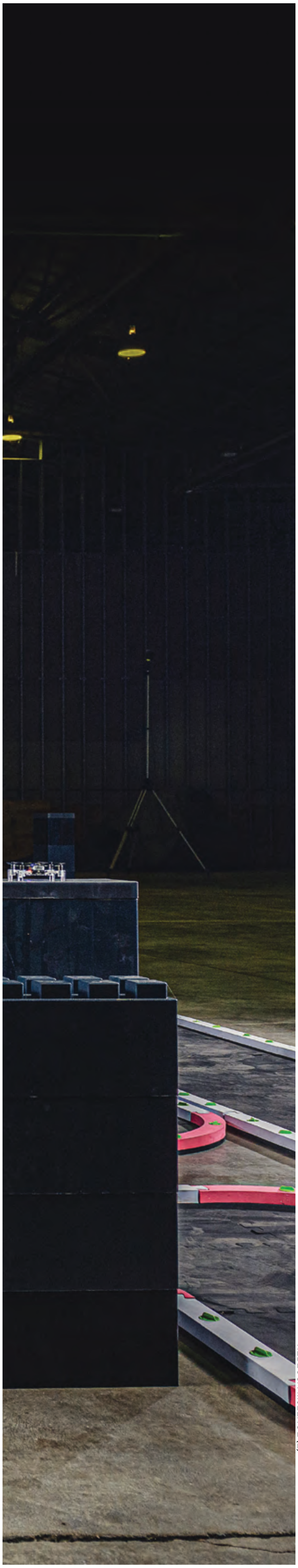


'A VERY, VERY UNIQUE FACILITY'

State-of-the-art motion capture system opens door for new grant and research opportunities, teaching and educational environments



There's no other university facility quite like this one. From its precise motion capture system, down to 1mm, to its unobstructed space in Hangar 4, the Purdue UAS Research and Test (PURT) Facility offers unparalleled technology in support of the largest indoor motion capture system in the world. (Rebecca McElhoe)



Even now, as James Goppert looks across 20,000 square feet inside Hangar 4 at the Purdue University airport, he still can't quite believe what has been done.

The 50 Qualisys motion capture cameras mounted on beams on the ceiling, precisely tracking movement below to the millimeter.

The 10 cameras mounted on tripods, perfectly placed to augment the ceiling cameras and exactly angled to capture the unmanned aerial vehicles (UAVs) zipping around the facility, weaving in and out of a scaled urban environment.

The swarm of miniature Crazyflie drones at his disposal, from Bitcraze with state-of-the-art active motion capture boards from Qualisys.

The graduate students conducting research, gathering data and building algorithms on laptops and then seeing those algorithms played out in real time, right in front of them, in the motion capture environment.

The aeronautical and astronautical engineers intermingling with computer science majors, aviation technology students popping in to test drones, mixing with electrical engineering students, providing the ultimate multidisciplinary environment.

It's everyday life in one of the most unique university facilities in the country.

The Purdue UAS Research and Test Facility (PURT) is the largest indoor motion capture system in the world and offers novel capabilities to match: In its 100-feet-by-180-feet contiguous volume, in totality of camera coverage, in the preciseness of those cameras, in its ability to not only fly large swarms of drones but also simulate hundreds more with virtual reality, in its ability to create simulated images for VR and augmented reality to construct mixed-reality environments.

"It's got the educational element, as well as a lot of community outreach, and it's also very integral for research," said Goppert (BSAAE '07, MSAAE '11, PHD AAE '18) the facility's managing director.

In 2018, this was only a vision.

EARLY DAYS

Goppert had just completed his PhD work in the School of Aeronautics and Astronautics when he heard about the idea to develop an unmanned aircraft systems (UAS) research and test facility. His industry work in robotics and doctorate work analyzing vulnerabilities in unmanned vehicles and how to successfully detect and counteract them made him an ideal candidate to assist in setting up the facility. Then-head Tom Shih offered Goppert the job, tying in helping to teach dynamics and control courses as well. But being part of the lab played a large role in Goppert staying in West Lafayette.

"As a more practical guy, I get to go in the lab and work with students on hands-on robotics and teach them how to do programming and teach them how to debug when a drone doesn't fly and get the soldering iron out when I have to," Goppert said. "Not many people get to be a managing director of a facility that's across all of Purdue. Even though aero/astro is in charge of it, we collaborate with many other departments in conducting state-of-the-art drone research. I think that's why I love it."

Early on, the idea was to develop a facility that would help Purdue stand out and be unique with an emphasis on project-based learning. But they had to figure out where to put the lab.

It was Shih's idea to look at Hangar 4. The group soon realized it was the "sweet spot" because it had bus access, was the largest facility they could get and had "the really cool atmosphere of being at the airport which all went in to play there," Goppert said.

Goppert investigated what other universities offered, especially ones that had indoor setups, and he soon realized Purdue's location at Hangar 4 could be the largest motion capture indoor environment. As he was looking to secure the equipment, he asked companies if they'd installed anything in this type of square footage before — and how

AAE Professor Inseok Hwang said PURT's novel capabilities have produced research grants that likely wouldn't have been secured without the facility.

REBECCA McELHOE (2)

Being part of PURT played a large role in James Goppert staying in West Lafayette after earning his bachelor's, master's and doctorate degrees in AAE. He's now managing director of the facility.

many cameras they'd realistically need to cover such a space.

By Fall 2019, vendors were coming to West Lafayette from all over the world to offer demonstrations. Goppert brought in the collegiate drone racing team at Purdue to fly around the facility "as fast as possible" to stress test all the camera systems. Ultimately, Swedish company Qualisys won out, in part because they'd shown their cameras could hold up to the conditions in the Midwest's variable temperatures at the University of Michigan's outdoor facility. Even though Purdue's facility is indoors, the hangar is "basically a barn," Goppert said, so the cameras needed to be able to sustain tough conditions and be extremely weatherproof.

And, most importantly, they needed to provide ultimate performance: The lab only was going to be as valuable as the accuracy of its measurements from the motion capture system.

The biggest test came after the first 54 high-resolution cameras were installed on the massive beams and mobile tripods within the hangar. Goppert said Purdue lucked out in that the 1960s hangar was so overbuilt there was very little deflection in the wind. Still, Qualisys was expecting the facility would get calibration errors of around 3 millimeters.

"It turned out we did a lot better than they thought was possible," Goppert said. "As we move this wand around the entire space, all the cameras agree on the solution of where the wand is with a standard deviation of 1 millimeter. That means in that entire space, which is basically half the size of a football field, we can tell where we are down to a millimeter, which is crazy."

And, with that, PURT transformed into an indoor lab no other university can match.

Motion capture enables a lot of robotics and the ability to create the elements. There's an ability to detect when the algorithms are giving the right answer and have a ground truth. That allows researchers to find errors, compare algorithms and know what the right answer is so they can know which algorithm is doing a better job.

Because the facility is indoors, there is no GPS. But the motion capture system and its down-to-the-millimeter precision provides the ability to simulate sensor data inside. It's easy to construct a fake GPS signal that actually degrades and adds some noise like GPS would have.

Its sensors also can simulate video streams, which means instead of a drone having an on-board camera that is seeing what it's actually seeing in the facility, researchers can give it a fake digital camera image that is streamed over Wi-Fi to the vehicles. Then, the vehicles see through "virtual reality goggles" whatever researchers want them to see.

"That allows you to do really cool things where you can make the vehicles think they're in whatever environment you want to, visually or with GPS signals or any other signal we'd want to create and feed to the drone. It's a controlled environment at the same time, which means we don't have to worry about FAA certifications."

RESEARCH

The novel capabilities have produced research grants that likely wouldn't have been secured without the facility.

AAE Professor Inseok Hwang is principal investigator on a three-year, $2.3-million grant from the Technology Innovation Institute in Abu Dhabi to study the application of secure drone swarms in urban environments. Hwang, Goppert and Dongyan Xu, the Samuel D. Conte Professor of Computer Science, were tasked to make sure drones and their systems could operate securely, safely and efficiently in the United Emirates capital.

The project required expertise in autonomous vehicles, control, sensing, virtual reality and security.

Goppert built a mixed reality environment, combining a virtual reality urban environment with a scaled physical model of the city. The drones fly and navigate the city, and the environment can be programmed to simulate a wide range of settings, including weather, traffic and urban development, to test the drones' applicability and agility.

With autonomy, though, comes risks of hackers and complications between interacting agents. Hwang and Xu have a multitiered approach from the cybersecurity and robustness standpoint. Hwang is developing a mathematical model and using the control theoretical solution approach, assessing potential cyberattacks on the systems and working to design a controller in such a way that the systems becomes more resilient to attacks. Xu is investigating from the cyber perspective of security, encryption, authentication and peer-to-peer communications.

Neither Hwang nor Goppert is aware of any other research being done using mixed reality to this scale.

"The selling point was our facility," Hwang said of the grant. "We're not just developing the algorithms and numerically testing it on a computer. On top of it, we actually fly the vehicle, and real tests can be done. One of the goals is to develop a mixed reality environment where the vehicle actually is flying in empty space but it believes it is flying through a city.

"Such things could not be done before PURT. A small lab could not accommodate that because it doesn't have the scale. But this is a huge indoor facility so we can implement and actually test it so that these sponsors get perspective. They get real results rather than nice movies or nice plots."

Another bonus: Testing can be done with a single vehicle as well as swarms — but not all of the swarms need to be physical drones. Though a larger group of vehicles can be physically flown inside the lab because of its size — especially because the old hangar offers a massive unobstructed space — hundreds could be added through mixed reality.

"An individual faculty member may have a small lab, but they can only fly a small number of drones. But this can accommodate up to 100, and even more because we have a mixed reality," Hwang said. "There may be 50 physical vehicles actually flying, for example, with an additional 250 vehicles flying in the virtual environments, harmoniously together. The number of the vehicles, there's not any limit there. Not everything is a simulated environment, but a significant portion actually fly."

A scaled urban environment also will play a key role in Purdue's work on the multidisciplinary team selected by NASA's Aeronautics Research Mission Directorate grant through its University Leadership Initiative program. Purdue's group, which received about $2 million of the team's $8-million grant, targeted the "secure and safe assured autonomy" thrust, and the team's topic is "Assured Autonomy for Aviation Transformation."

REBECCA McELHOE

PURT provides the ultimate multi-disciplinary environment with students from various disciplines conducting research in the facility.

Purdue work is focusing on innovations in secure and robust distributed autonomy and control algorithms applicable to both cargo and future passenger carrying advanced air mobility, said AAE Professor Daniel DeLaurentis, Purdue's PI on the project.

As vehicles are made more autonomous, they also need to be safe and more robust. Goppert's piece is looking specifically at model checking and verification and validation of the auto-pilot software for the vehicles.

"When they fly downtown, they're around buildings. As wind gusts increase, how do you quickly and safely plan trajectories for these vehicles and determine when it's too windy for them to fly?" Goppert said. "To do that in the real world, we'd have to actually have a fleet of vehicles flying around a city. That's not safe or practical to do while you're developing the algorithms. This kind of controlled scaled urban lab setting is a great place to prototype because it can allow us to transition from pure simulation toward final deployment without having to do the leg work of actually flying a fleet of UAVs in a city. We can look at the complex interactions and if the mathematical models we're creating actually are validated in the real world."

Said Hwang, "We built this emulated scaled city environment to test the developed algorithms and what can really go wrong, and it cannot be done in the computer environments yet. So that's another interesting aspect."

FUTURE

Goppert and Hwang plan on continuing to push the possibilities in PURT.

Because of the size of the hangar, Goppert had a senior design class designing airplanes last year that could fly in the facility.

"The ability to actually fly fixed wing aircraft in a motion capture environment is something that's really unique," Goppert said.

Having an open-air wind tunnel is a possibility, too, because the facility is so large and there's a lot of open space to get air flowing. That'd open the possibility to control wind around the objects within the environment. They could inject fog, virtually or by having a dry-ice machine pumping fog into the space.

"Being able to manipulate the environment of the drone like that is very interesting to us," Goppert said.

The size also means vehicles can go fast and don't have to have the largest turning radius. That's not the case in a small building with a motion capture system.

There's certainly more to come.

"It's more impressive than I expected it'd be within a short period of time," Hwang said. "This is a very, very unique facility that belongs to Purdue. It opens up the door for the new grant opportunities, research opportunities and even teaching and educational environments as well, student-led. That's the whole goal."

VINCENT WALTER

VINCENT WALTER (3)

RACE TO NET-ZERO

COULD HYDROGEN HOLD THE SOLUTION TO SUSTAINABLE JET FUEL?

REBECCA McELHOE

As more countries around the world commit to net-zero carbon emissions by 2050, industry groups are following suit. Among them, the members of the International Air Transport Association who announced a commitment to take action to cut emissions among global airlines in October.

Aviation accounts for about 2.5 percent of global carbon dioxide (CO2) emissions, the greenhouse gas that's a major contributor to global warming. While the automobile industry has begun shifting to hybrid vehicles and electric vehicles to reduce emissions, similar approaches within aviation prove more challenging to implement.

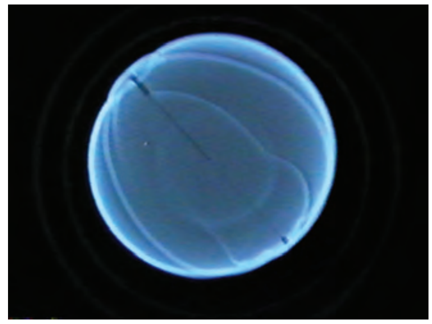
"Electric and hybrid engine systems might work for very small airplanes but they are currently impractical for large passenger aircrafts that require a fuel with high energy density," said Li Qiao, professor of aeronautics and astronautics. "Even the best lithium-ion batteries available today have only less than one-tenth the energy density compared to liquid hydrocarbon fuels."

Every ounce counts when calculating an aircraft's payload. The amount of batteries required to power a large passenger plane would drastically increase the plane's mass, requiring more lift. Alternative fuels such as ethanol require more space, which would increase the plane's volume and necessitate a massive fuel tank that would increase drag.

To meet the ambitious goal of net-zero emissions by 2050, the aviation industry needs to identify alternative fuels that provide comparable ratios of energy density as the current kerosene-based jet fuels.

"There are two key factors critical to innovating low-carbon technologies over the next few decades," Qiao said. "One is new engine and aircraft designs that enhance efficiency. The other is developing sustainable aviation fuels, such as hydrogen."

While liquid hydrogen shows promise as a light-weight sustainable fuel, its physical and chemical properties present challenges to traditional aircraft engine design, which is why understanding how hydrogen behaves during combustion is essential to determining its feasibility as an alternative fuel. Qiao's propulsion and energy lab studies how fuel burns using high-speed optical methods and advanced laser diagnostics.



A hydrogen flame showing a blue color obtained from an experiment in Qiao's propulsion and energy lab.

"Hydrogen is a very interesting fuel," Qiao said. "It has high reactivity, fast diffusion, short ignition delay and fast flame propagation speed. All of these unique characteristics will lead to combustion design challenges. To address these challenges, we must understand fundamentally the chemical kinetics, turbulence and chemistry interaction, thermoacoustic instabilities and flashback of hydrogen."

Hydrogen has the highest specific energy per mass of any fuel, however its low ambient temperature density results in a lower energy density by volume which presents its own challenges for onboard storage.

"Using hydrogen as a replacement for liquid transportation fuels is a challenge for aviation applications," Qiao said. "The volumetric energy density of hydrogen must be significantly increased through revolutionary storage technologies."

Whether hydrogen is the solution or some other alternative emerges, Qiao is confident in the industry's ability to meet the goal of net-zero emissions by 2050.

"Meeting the critical challenge of climate change represents tremendous opportunities for scientific breakthroughs and technological innovation. Partnership between industry, government labs and academic research intuitions is key to finding novel solutions to meet increasing energy demand and reduce emission."

COMPUTATIONAL MODELS AID IN PREDICTION OF MATERIAL FAILURE, FATIGUE

Reliable performance of aerospace materials is crucial to maintain safe and efficient operations while aircrafts hurtle through the stratosphere. Traditional methods of testing and evaluating materials for life limiting features are cumbersome and time intensive.

A research team led by Michael D. Sangid, the Elmer F. Bruhn Professor of Aeronautics and Astronautics, has developed a computational methodology to execute predictive models to account for the lifespan of materials, including nickel-based superalloys, titanium alloys and structural composites. Four examples are provided in terms of addressing the reliability of materials in an attempt to improve aircraft safety.

As a first example — many times, these life limiting features take the form of intermetallic inclusions, which are impurities in the material. Since these inclusions represent rare events — needles in the haystack — it is difficult to test a sufficient quantity of material to understand their effect on the material's life. Sangid's group uses computational techniques, known as crystal plasticity, to model materials with inclusions as well as experimental techniques using high energy X-rays to characterize the response of the material and the inclusions during loading.

By computationally modeling inclusions in the material, the research team can account for more broad scenarios, thereby developing a richer probabilistic approach to the material's capabilities to complement traditional experiments.

"A lot of the methodology done to date relies on technology that's 70 years old," Sangid said. "Our methodology doesn't rely on large-scale testing campaigns focused on making and breaking of parts. Developing the material in a virtual setting and computationally testing the materials results in time and cost savings when compared to traditional techniques."

Second, Sangid's research group is also applying computational methods to better understand the phenomenon of cold dwell fatigue in titanium alloys, a commonly used material in aircrafts. At lower temperatures, hold times on titanium materials reduce the lifetime of the material and can result in premature aircraft failures. "Once we understand how the material's microstructure is responding under certain conditions, we can develop computational approaches to predict this behavior in an effort to manage titanium cold dwell behaviors, in order to mitigate failure," Sangid said.

Third, "As we start to introduce new materials and manufacturing processes into service, we must have ways of qualifying these materials can operate safely," Sangid said. "There are many operating conditions and environments that we might not fully understand or have experience with, so rigorous testing in our labs that mimic in service flight operation, as well as computational modeling, provide an understanding of the failure mechanisms and the associated lifetime for the material."

Some of the new materials the group is testing include ceramic matrix composites and metallic alloys made through additive manufacturing. They're also evaluating more familiar materials, such as carbon fiber reinforced polymer (CFRP) composites which have been used to build aircrafts for the past two decades.

Service usage and laboratory testing have recently revealed CFRP materials to be susceptible to slow crack growth associated with fatigue. Sangid's team is developing a fatigue criteria using X-ray techniques and computational approaches to identify the remaining lifetime for the aircraft's CFRP components, in order to proactively manage the inspection and replacement of susceptible parts.

Sangid's industrial background, witnessing the effects of material failures in a lab setting and understanding the limitations of testing, drives his passion for improving safety in the aerospace industry through the development of new computational methodologies.

"When it comes to aircraft, we have the smallest margins for risk of nearly any other industrial sector," he said. "At the same time, any overly-conservative design results in excessive fuel consumption and exhaust byproducts."

JOHN UNDERWOOD

JOHN UNDERWOOD

ON A MISSION FOR BETTER MANUFACTURING

JOHN UNDERWOOD

Dianyun Zhang didn't plan on spending her career doing composites manufacturing.

She learned to love structures because of how critical it is for any aerospace engineering application, putting maximum effort into reducing weight to save cost and influence efficiency in aircraft and spacecraft.

But Zhang had been leaning more toward the structure performance side, not in the manufacturing itself. Until a project sponsored by GKN Aerospace while she was an assistant professor of mechanical engineering at the University of Connecticut altered her career trajectory.

Carbon-fiber reinforced composites have been around since the 1960s but only now are being used in larger applications, like in commercial aircraft.

"It's quite interesting," Zhang said. "We always get encouragement from industry coming to us for help and saying, 'This is some issue they would like us to solve on the fundamental side.' Even though they have lots of hands-on experience and know how to resolve it in a very practical way, they still would like to develop a fundamental understanding of the root cause of the issue so they can save time and money for their future manufacturing practice.

"This is a real-world problem that's not easy to solve. You're just going forever. Once you try to solve the problem, you find another good research area to pursue."

Zhang's research goal is to develop an integrated computational materials engineering approach by integrating physics-based and data-driven models to predict manufacturing-induced defects and the processing-microstructure-property-performance relationship of composite materials. Her focus is on multiphysics process modeling, multiscale modeling methods and progressive damage and failure analysis across different material length scales.

"It's a very exciting technology," Zhang said. "Over the years, we're trying to have a better understanding of the mechanics. Understanding the failure behavior. Now we're also trying to address the manufacturing issue because we think one of the reasons we still have to put pretty large safety factors for our design is we don't really have a good control of the manufacturing process. It ends with defects and the variability of the processes. We kind of over-design the structure.

"That's why I think in this area our research efforts trying to have a high-fidelity computational model can simulate both the manufacturing process and its performance and, eventually, we can really use the composite more efficiently to further reduce the structure weight."

There certainly are problems to solve.

Despite the growing market demand for advance composites, grand challenges exist for the United States to be a leader in composites manufacturing. Reducing cycle time and process variability are the most crucial technical challenges, and workforce development is the most significant logistical barrier to grow the U.S. composites manufacturing industry.

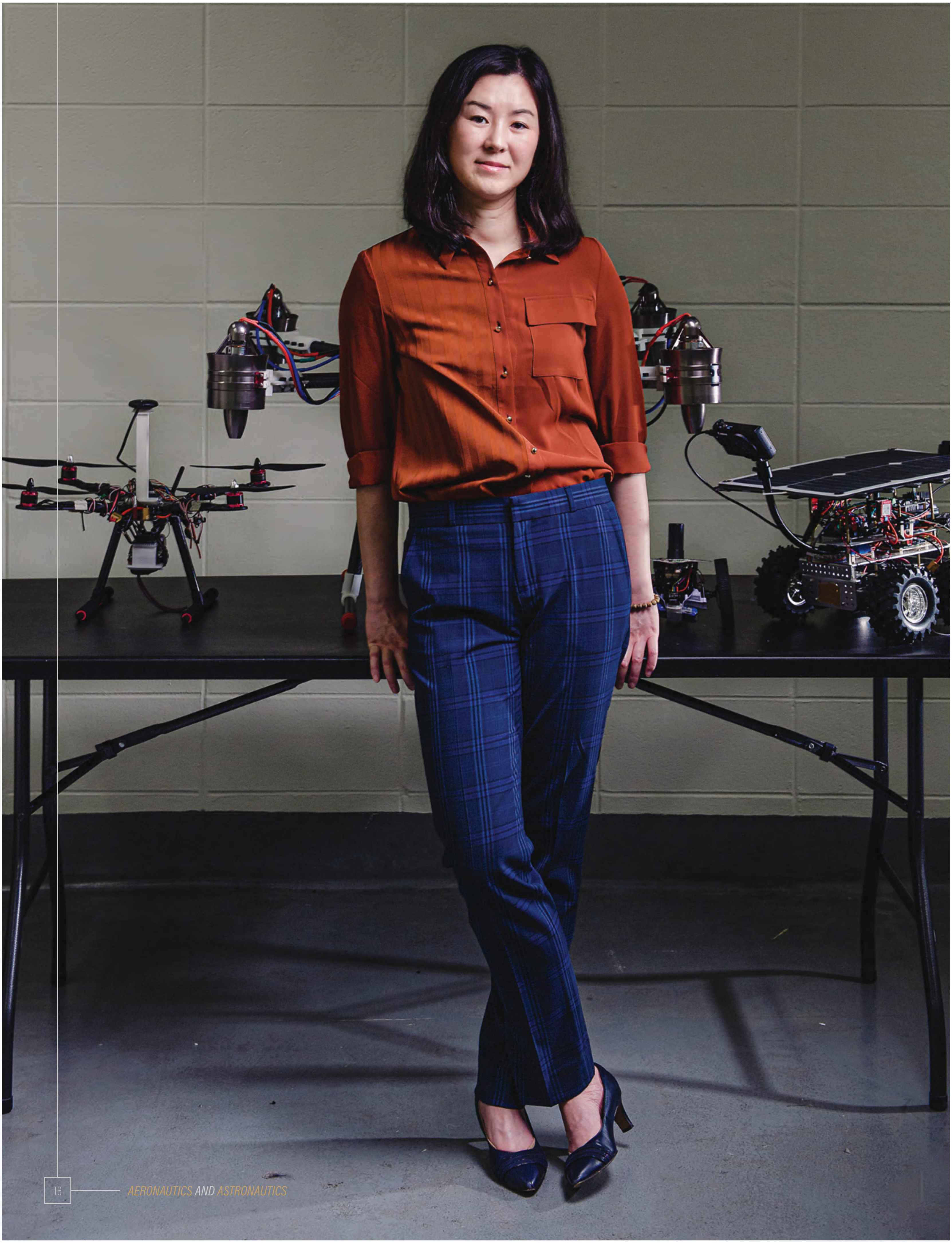
Zhang, who joined the AAE faculty in fall 2020, is working to overcome those challenges by integrating a research and education plan to investigate the fundamentals associated with composite manufacturing processes and build a workforce pipeline.

Composite manufacturers currently are heavily reliant on in-house experience and trial-and-error approaches for process development, resulting in high manufacturing costs and long produce development cycles and limiting the innovations for new process and part decision. There are culture barriers between the manufacturers, material scientists and structural engineers, making the adoption of the process simulations a challenge. Zhang wants to create a composite ecosystem to intimately connect those groups, accelerating the use of lightweight materials in vehicle structures, leading to high fuel efficiency and low emissions.

"This is something we would like to try to do now, to simulate the manufacturing process, eventually link toward the structure performance so that the manufacture, the OEM, like an engine or aircraft manufacturer, they really can think about a design problem together," she said.

Zhang is finding the Composite Manufacturing & Simulation Center, a Purdue University Center of Excellence, at the Indiana Manufacturing Institute the perfect place to conduct research for her ongoing projects.

"Here we literally get everything I need for the experimental and simulation parts of my research," said Zhang, sitting in her office at IMI. "We can do manufacturing characterization and also through the software support. With the computational resources and the experimental resources, this is just a fantastic place where I can carry on my research."



Destination Mars

NASA-funded Project Aims to Develop Guidance System for Manned Mission to the Red Planet


REBECCA McELHOE

After the Perseverance rover successfully touched down on Mars in February 2021 following a landing sequence scientists refer to as "seven minutes of terror," the NASA mission was widely celebrated. It wasn't just that Perseverance is the largest, most advanced rover NASA has ever sent to another world. It's that landing on Mars is extremely difficult.

"The fact that NASA has already been successful landing rovers on the surface of Mars a couple of times is very exciting," said Ran Dai, associate professor of aeronautics and astronautics. "In the next 20 years, they plan to send astronauts to Mars. However, there are a number of technical and safety challenges that must be overcome before a manned mission would be possible."

A spacecraft carrying a human crew has a much higher payload than a robotically operated rover. And once it reaches the Mars atmospheric boundary, the spacecraft would be traveling at supersonic speed without much time to decelerate the vehicle. Because the atmosphere around Mars is much thinner than that of Earth, crafts can't glide gently to its surface using only the atmospheric drag.

"Not only will these vehicles be decelerating from a super high speed to zero speed in a short period of time, the spacecraft also needs to land at a specific preassigned location," Dai said. "There may be areas that have already been explored by robots with stations set up. We don't want to just land a space vehicle anywhere on the Mars surface. So not only is there a need for controlled decelerations, but also precision."

As a craft enters the atmosphere, the first phase of deceleration is achieved through aerodynamic drag. During the second phase, the propulsion system is engaged to further decelerate the vehicle. With a robotic rover, once the craft reaches a certain altitude, a parachute can be deployed. With a high payload spacecraft, a parachute would not work. It would require significant fuel consumption to guide the propulsion system to generate the desired thrust necessary to manage a safe landing in an exact location.

"It's a complicated process," Dai said. "We have to consider all three objectives, deceleration, a highly precise landing and fuel consumption. That is our focus, to achieve the vehicle goal in the most optimal way and complete a safe and fuel efficient landing."

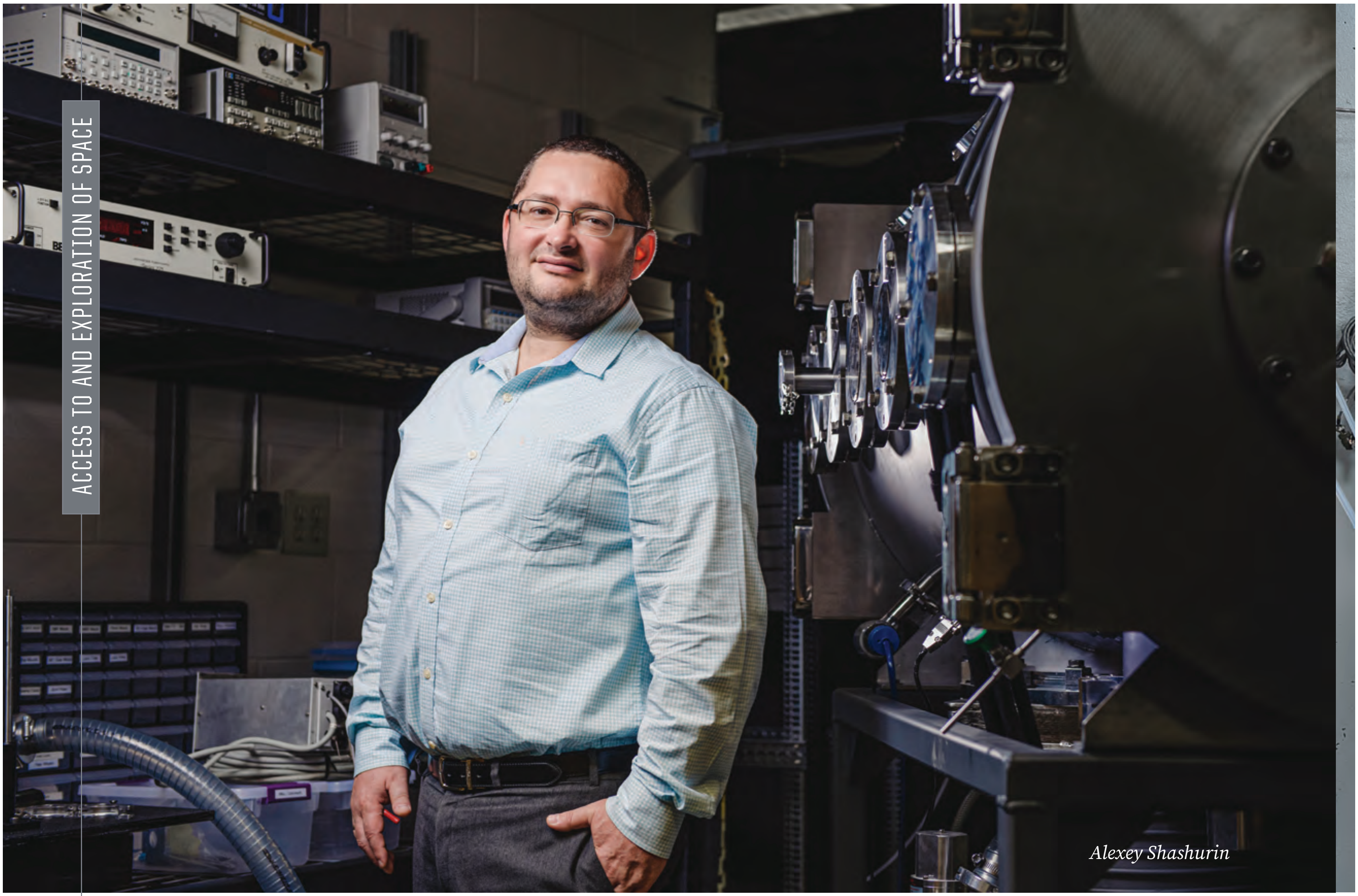
Dai received a three-year Early Career Faculty for Space Technology Research Grant from NASA to investigate precision planetary landing. The nearly $600,000 grant funds her research to develop an optimized spacecraft landing approach with powered descent.

Titled "Optimized Entry and Powered Descent Guidance for Precision Planetary Landing," the project aims to develop a highly implementable guidance approach that optimizes the end-to-end complete entry, powered descent and landing trajectories in real-time toward the fuel-optimal and precise landing.

"We work in close collaboration with NASA engineers," Dai said. "In addition to biweekly meetings with a NASA manager to report our progress, we also have an annual meeting with a group of NASA scientists and engineers from various branches."

Dai and her team have spent the past few years focused on designing computational algorithms to operate the guidance system. They are now building a small-scale test beta using drones to with an electronic propulsion system. The team will then implement their algorithms to see if they can create a simulated scenario that's similar to a Mars entry.

"For example, we can make our test beta climb to a high altitude and then dive down at a high speed," Dai said. "Then we can enable the guidance system and see if we can guide our customized vehicle to its assigned ending position. The test beta will help to verify our guidance algorithm. And maybe one day, our algorithms will be used in an actual Mars landing."


Alexey Shashurin

REBECCA McELHOE

Envisioned Dual-Mode Propulsion System Would Maximize Power and Efficiency

Chemical propulsion and electric propulsion systems offer clear, differing advantages and cater toward specific missions. But there's always a trade-off between consumption of propellant and the time to perform a maneuver. A chemical propulsion system can complete a maneuver very quickly, but it burns propellant. An electric system can do the same maneuver with a fraction of propellant but needs much more time to execute.

If a spacecraft had both chemical and electric systems — in a "dual-mode" system that combines both thrusters into one unit — an operator or computer could decide which system to use depending on the situation. If time allowed for a gradual maneuver, the choice would be the propellant-saving electronic propulsion system. If a quick maneuver was needed, the chemical propulsion system could help instantly with some extra cost, in terms of burnt propellant.

There isn't a current vehicle in orbit that uses such a chemical/electrical dual-mode system.

A pair of AAE professors is looking to change that.

Alexey Shashurin and Timothee Pourpoint are working to integrate chemical and electric propulsion systems into a dual-mode system to achieve the benefit of two operational scenarios: high-thrust/low-specific impulse and low-thrust/high-specific impulse.

"The bundle definitely makes sense," Shashurin said.

A chemical propellant in an electrical thruster would use a small amount of that chemical propellant.

"Finding the right architecture that combines as many of the benefits of chemical and electric systems in one unit is highly

Timothee Pourpoint

JOHN UNDERWOOD

challenging, but that's what makes this research so engaging," Pourpoint said.

Part of this work will include development of robust green propulsion systems, allowing for long-lasting operation in lunar orbits. A current focus is on the design of the chemical monopropellant thrusters operating with "green" chemical propellants at thrust level. The high density of the propellants and their unique chemical composition extends to additional propulsion capabilities, such as electrospray thrusters and pulse plasma thrusters. Recent advances in pressurization control techniques allow the combination of these technologies into a single feed system.

Such an approach could shift the paradigm in how CubeSats are propelled, allowing the best of both worlds from chemical and electric systems.

Purdue University is the ideal place to make such giant leaps with Pourpoint's lab at Maurice J. Zucrow Laboratories and Shashurin's Electric Propulsion and Plasma Laboratory in the Neil Armstrong Hall of Engineering.

"It's clear that we have a unique opportunity here to use a range of propellants that we can use at Zucrow toward that sort of application, and very few universities can do that," Pourpoint said. "We literally go down the road, between each other's labs, and iterate rapidly between configurations."

AAE graduate student Lee Organski will support the work as part of an Indiana Space Grant Consortium Fellowship. Organski will be co-advised by Pourpoint and Shashurin.

"FINDING THE RIGHT ARCHITECTURE THAT COMBINES AS MANY OF THE BENEFITS OF CHEMICAL AND ELECTRIC SYSTEMS IN ONE UNIT IS HIGHLY CHALLENGING, BUT THAT'S WHAT MAKES THIS RESEARCH SO ENGAGING."

– TIMOTHEE POURPOINT

Alumnus Todd Ely has been principal investigator on the Deep Space Atomic Clock since its inception in 2011.

NASA/JPL

DEEP SPACE ATOMIC CLOCK REPRESENTS REVOLUTION IN AUTONOMOUS NAVIGATION

Todd Ely's team already has demonstrated a trapped-ion atomic clock operating in space.

The Deep Space Atomic Clock's long-term performance from 2019-2021, hosted aboard the General Atomics Orbital Test Bed satellite, was an unquestioned success, showcasing its potential as a next-generation tool for spacecraft navigation, radio science and global positioning systems.

The set of requirements the team from NASA's Jet Propulsion Laboratory set out to achieve when it first started the project were "far exceeded in many ways," AAE alumnus Todd Ely said, in that DSAC was more than an order of magnitude more stable than the atomic clocks that are flying in the GPS constellation today, on short-time scales under a day and also long-time scales as well. DSAC also had the lowest recorded drift in a space clock that had been deployed to date.

"The clock has done some really great things, and people are beginning to recognize that," said Ely, who has been principal investigator on the project since its inception in 2011.

NASA selected a follow-up to DSAC in June 2021. Built by JPL and funded by NASA's Space Technology Mission Directorate, the Deep Space Atomic Clock-2 (DSAC-2) will fly on the VERITAS mission to Venus in the late 2020s.

The goal of the initial DSAC was, generally, simple: Get it *to work* in space and characterize its performance in low-Earth orbit. The next step is more ambitious, applying what was learned from DSAC to potentially revolutionize deep space navigation. Some tweaks will be made in the second iteration in order to reduce size, weight and power to make it more amenable for future use.

"We want to design DSAC-2 so that somebody would want to build it again and deploy it in a number of potential uses, whether it be for NASA, DoD or even commercial uses," Ely said. "As we go out farther into space, whether we start having more presence at the Moon, going to Mars, if we have a sustained presence at those places, especially if humans start going there, you're going to want to have GPS-like equivalents in those types of places. DSAC would be an important element in any of those infrastructure elements."

Ely's Purdue background has him well-suited to lead those developments.

A former student under Kathleen Howell, the Hsu Lo Distinguished Professor of Aeronautics and Astronautics, Ely (BSAAE '86, MSAAE '88, PhD AAE '96) has developed deep-rooted knowledge and experience in astrodynamics, whether it be in orbital mechanics or in navigation. Throughout Ely's career, he's investigated new ways to do navigation, whether it be adaptive navigation or, in DSAC's case, stepping stones to what is called autonomous navigation. DSAC will play a role in the latter, he hopes.

Because of DSAC's low sensitivity to variations in temperature and magnetic fields and robustness to radiation, it's particularly amenable for space. The level of the space clock performance will enable one-way navigation in which signal delay times are measured in situ, making near real-time navigation of deep space probes possible and useful for radio science investigations of planetary atmospheres, gravity fields and more.

Atomic clocks are a key component for accurate one-way space navigation, allowing spacecraft to know their own speed and trajectory rather than needing to bounce radio metric signals back and forth between the spacecraft and a ground station on Earth. That process, which can take many hours for deep-space missions, always will be an option. But clocks onboard spacecraft with superb stability enable precise in situ measurements (at the nanosecond level or better) of distance needed for many deep space navigation applications. An error of even one second can mean the difference between landing on Mars or missing it by hundreds of thousands of miles.

"The ability to have an onboard navigation solution will be important for risk reduction and ensuring health and safety of astronauts," Ely said. "With DSAC, you can make that measurement on board. If the measurement is on board and you pair that with a navigation system that could process that data, then you have an onboard potentially autonomous navigation solution."

It could be many years before Ely knows the results, but he expects to keep enjoying the "amazing ride."

"It's been a phenomenal job," he said. "It's one of those satisfying jobs where you envision it, you plan it, you build it and you execute it and then you work hard on figuring out ways where it could do best in the future. I've been able to participate in all of those activities. The team that has been working on it has been phenomenal.

"I hope to keep on doing it in the future and make a difference. I think that's what we all start out our education saying. 'That's cool stuff to get involved with.' If you're lucky, you get to do cool stuff. And I think I've been lucky."

NASA

The electromagnetic spectrum is increasingly congested, and future communication systems likely will have to be able to rapidly "jump" to a different frequency when there are other devices operating at their main frequencies.

In military applications, electronic warfare involves the ability to jam or damage adversary's electronic equipment, but such an ability also can be used by the adversaries. A high-powered microwave pulse can destroy electronics on a military airplane, for example, or jam critical GPS guidance systems, wiping out the ability to receive or transmit communications.

But what if those pilots were able to switch to a different frequency quickly instead of being limited to one option, while closing the "original" communication frequency? Then the pilots could still communicate and send signals even when subject to electronic attack.

Motivated by such applications, AAE Professor Sergey Macheret is working on the ability to control electromagnetic interactions — by using plasmas.

Macheret's group already has demonstrated a tunable plasma antenna with "very good performance." They've also proven they can substantially change a plasma-based capacitor purely electronically, which is very quick, using plasma, changing its properties through plasma "tuning" instead of moving the capacitor plates mechanically, which is very slow, as done in conventional high-power frequency systems.

The next step: changing the properties on the plasma *inside* the antenna, a promising idea in the ability to control electromagnetic interactions.

"It turns out you can manipulate and change these properties for each of the elements of an antenna array individually. Now you can think about many of these elements in an array, and you can change the properties of the whole array that is so much greater than each of these elements, in terms of your ability to manipulate electromagnetic waves. I think it's pretty exciting," Macheret said. "For me, it's sort of like music, that it has infinite variety based on a very finite set of elements. That's aesthetically pleasing. And, of course, potential applications are tremendous. So that's an added benefit."

Macheret has two funded research projects connected to the work, one with Lockheed Martin and another as part of the Department of Defense Multidisciplinary University Research Initiative with the Air Force Office of Scientific Research.

For the Lockheed Martin work, Macheret is co-principal investigator with Dimitrios Peroulis, the head and Reilly Professor of the School of Electrical and Computer Engineering. Their effort is to mature and advance the understanding of the capabilities of plasma-based antennas and arrays. The work is intended to explore the limits of miniaturizing the plasma radiating elements and the correlation between size and performance through analysis, simulation and experimentation.

"The intent is to demonstrate, for the first time, all of the miniature plasma antenna elements," Macheret said. "So far, we have worked with big, macroscopic plasma antennas. The question is, can we miniaturize the antenna elements and can we demonstrate an antenna array, with multiple elements independently controlled?"

By independently controlling a number of elements in an array, different phases can be applied so that a transmitted signal can be directed specifically where it's needed and can be scanned.

After design analysis, Macheret will develop a single plasma radiator design. A minimum of four radiating elements will be fabricated, and individual radiators will be tested to measure and quantify their beam patterns.

Ultimately, a flat plate array with a minimum of 16 elements will be designed, fabricated and tested. Testing will measure the combined beam pattern of the array, the array efficiency, frequency bandwidth, thermal stability and pulse width response characteristics.

"The question is how would the array made of small plasma elements perform?" Macheret said.

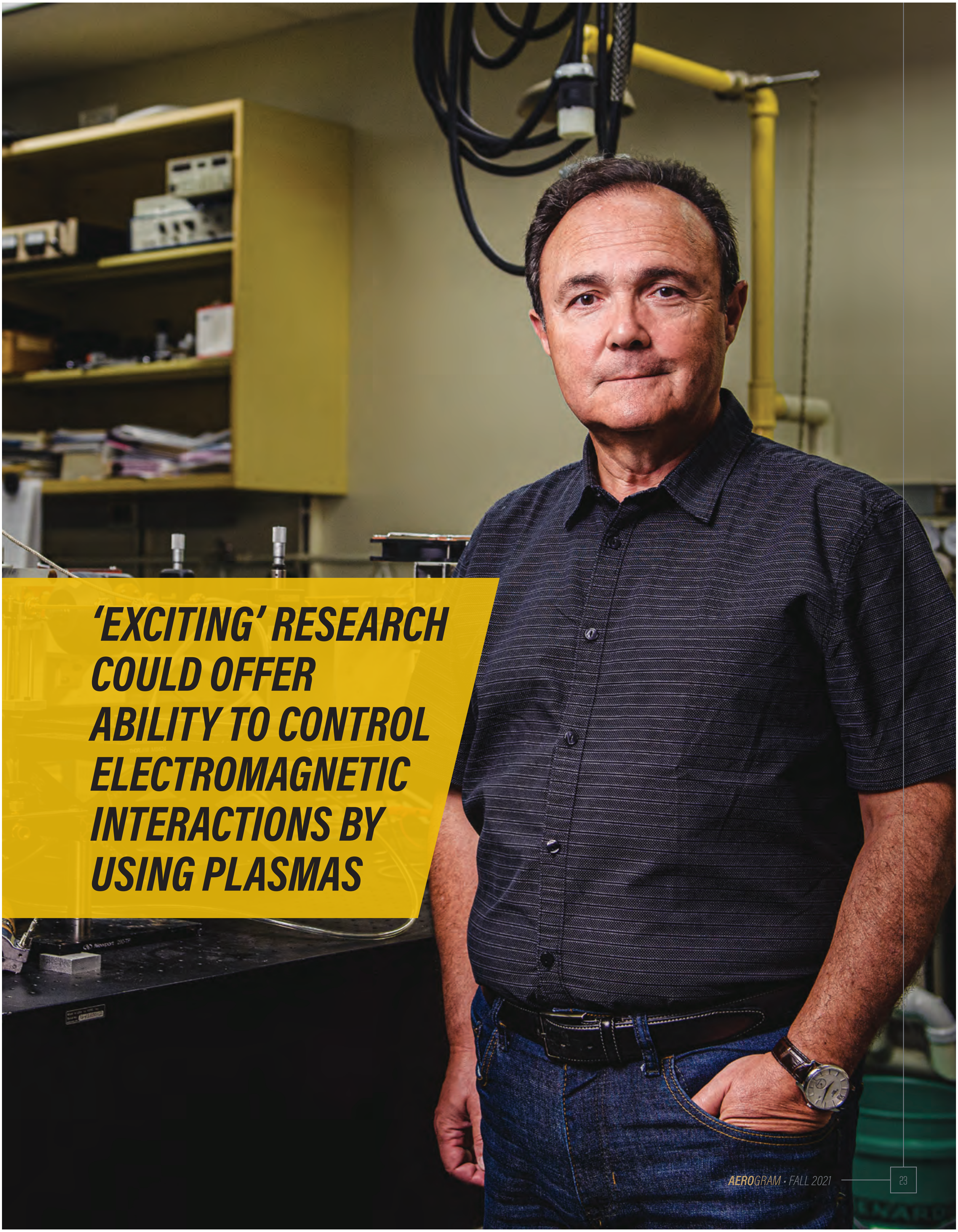
The MURI grant, which includes six investigators from three universities, is for "topological plasma structures for control of electromagnetic interactions." Macheret is the PI, and the collaboration will include overlap between plasmas and the booming research area of metamaterials, marrying the two areas together to "synergistically get something that is impossible to get separately."

Based on novel principles of plasma tuning and control and multiphysics modeling and inverse design, the group will study and develop systems that would offer unprecedented ways to manipulate electromagnetic interactions, enhancing DoD capabilities.

A key thrust of the effort, led by Macheret, will be in kinetics of plasma generation and on-demand control, in order to develop a fundamental understanding and innovative techniques to vary the electromagnetic properties of plasma discharges.

"Plasmas could provide some very flexible and tunable and interesting properties, which, when you include them into those metamaterial structures, would produce some new functionality, new ways of manipulating electromagnetic waves," Macheret said.

REBECCA McELHOE



'EXCITING' RESEARCH COULD OFFER ABILITY TO CONTROL ELECTROMAGNETIC INTERACTIONS BY USING PLASMAS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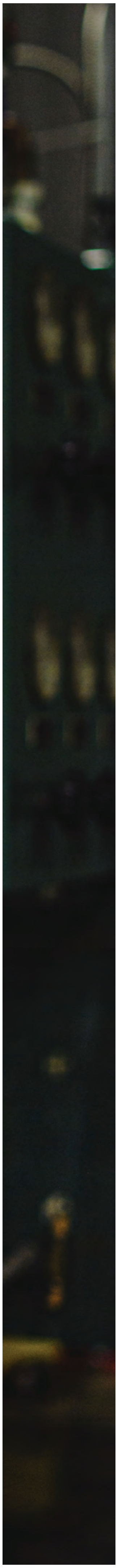


REBECCA McELHOE

Computational Prototyping of Rotor Blades Speeds Design of More Agile, Efficient 'Flying Cars'

Flying cars have long been popularized as the transportation mode of the future. Thanks to technology licensed in part through Purdue University, the future of flying cars may be closer than we think.

"Before Henry Ford introduced the Model T, automobiles were a rarity that only the very wealthy could afford," said Wenbin Yu, AAE professor and director for the Composites Design and Manufacturing HUB (cdmHUB). "Prototypes for small-scale aerial vehicles already exist and they're capable of transporting people short distances. In the pursuit of making flying more agile through the commercialization of eVTOL, we will see a democratization of these flying cars. They will be affordable and accessible to the general public and will become as commonplace as cars."

Launched in May 2020, the United States Air Force's Agility Prime program is technology accelerator driving the commercial development of ORBs, electronic vertical take-off and landing aircraft (eVTOL). These vehicles hover on rotor blades and can be crewed, remotely piloted or autonomous. In addition to eVTOLs providing consumers a means of personal flight, they could also support the military in transportation, search and rescue, surveillance and possibly autonomous operations.

"The Air Force is ready to push this capability because there is a need for military vehicles that offer a balance of agility and speed," Yu said. "Helicopters used in the Army offer more agility than a fighter jet used in the Air Force but the fighter jet is much faster, yet the helicopter is quite loud. For operations where the Air Force might want a small crew that can be transported quickly and quietly, an eVTOL could offer the solution."

Yu is chief technology officer for AnalySwift, a leading provider of efficient, high-fidelity simulation software for the simulation of composite materials and structures. The company won a Small Business Technology Transfer grant from the USAF to develop an integrated computational blade engineering framework for the rapid insertion of high-performance composite rotor blades into personal-flight aircraft. The framework will lead to prototyped parts developed by project partner Hexcel and then tested by the Weber State University composites lab.

"Rotor blades made from composite materials are stronger and lighter than those made from traditional materials, while also offering optimal performance," Yu said. "But they can be very challenging to model. Our software enables the analysis of the rotor blade's engineering properties through computational optimization."

The VABS software created by AnalySwift drastically reduces the design cycle and time to market by saving orders of magnitude in design and analysis time. The development of VABS was continuously funded by the U.S. Army for more than three decades to address the challenges in modeling composite rotor blades in helicopters. In the years since, the accuracy of VABS in helicopters and the wind turbine industry has been extensively validated. Now, that same technology is being used to analyze the unique characteristics presented by composite rotor blades on ORBs.

"This technology saves time for companies developing eVTOL vehicles," Yu said. "The computational methodologies provide rigorous simulations of composite rotor blades in a less costly and time-consuming manner than competing methods and experiments. Currently, the development of these eVTOL vehicles is in the experimental phase. But in the near future, our software will enable the mass production of composite rotor blades for personal-flight aircraft."

ON THE HORIZON

‘WORLD CLASS’ HYPERSONICS AND APPLIED RESEARCH FACILITY WILL SOLIDIFY PURDUE AT FOREFRONT OF HYPERSONICS RESEARCH

Wide open land, filled with tall grass, weeds, crickets and a patch of large bushes and trees.

In August 2021, when Brandon Chynoweth walked in an indistinctive field near Maurice J. Zucrow Laboratories in the Aerospace District for a photo shoot, there could only be visions of what the vast land would become: One of the foremost research facilities for hypersonic test and evaluation in the world, designed to function at multiple security levels in handling proprietary research collaborations with government and industry.

Research Assistant Professor Brandon Chynoweth (MSAAE ’15, PhD AAE ’18) was tapped to design, develop and run the new Mach 8 quiet wind tunnel that’ll be housed at the new Hypersonics and Applied Research Facility in Purdue’s Aerospace District.

REBECCA McELHOE

Only five months earlier, the Executive Committee of the Purdue University Board of Trustees, acting on behalf of the full board, approved University planning, financing, construction and awarding of construction contracts for a new facility to house two hypersonic wind tunnels.

By November 2021, officials had broken ground on the Hypersonics and Applied Research Facility.

By 2023, the 65,000-square-foot, $41-million space is expected to be completed. It'll house the Hypersonic Pulse reflected shock/expansion tunnel (HYPULSE), donated by Northrop Grumman Corporation, and a newly developed and constructed Mach 8 quiet tunnel, which will be the first of its kind capable of collecting data at speeds greater than Mach 6.

The combination of two unique wind tunnel facilities in one state-of-the-art building will further separate Purdue from its peers in hypersonics research.

HYPULSE operates at high temperatures with a high-disturbance flow and will allow flight simulations at speeds ranging from Mach 5 to as high as Mach 40, while the Mach 8 quiet tunnel will be low temperature but have a unique low-disturbance test environment.

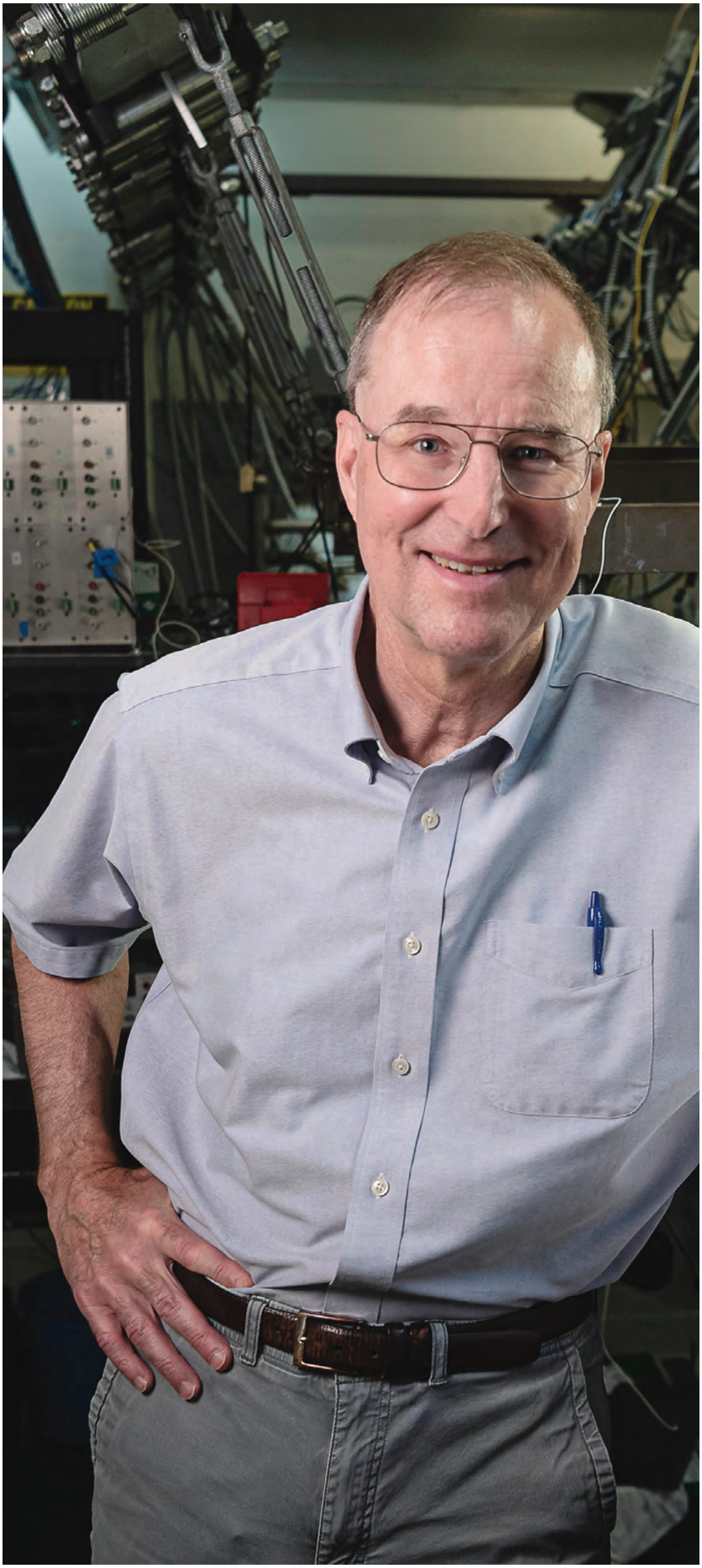
Because no one wind tunnel can truly simulate all areas of flight, by putting those capabilities together in one space, "this gives Purdue the ability to simulate both of the most challenging aspects of hypersonic aerodynamic testing on the ground," said Joseph Jewell, an assistant professor in AAE.

"It's easier to build a tunnel that's cold and high disturbance. Many universities have tunnels like that," Jewell said. "Knocking out either one of those, making it either low disturbance, like the atmosphere, or hot, like realistic re-entry or hypersonic flight in the atmosphere, that gets more difficult. So now at Purdue, adding HYPULSE and having the existing Mach 6 quiet tunnel and the new Mach 8 quiet tunnel, we'll be able to do both of those things. It's a big deal.

"With the full suite of capabilities we have now, we'll be able to do things that no other university can do."

Purdue's reputation in hypersonics is the main reason why it is here, on the verge of exclusivity, and why it continues to establish itself as a hub of hypersonic capabilities research.

"This facility will ensure that Purdue remains at the forefront of universities conducting research in hypersonics that will support national security needs and other efforts, like atmospheric re-entry of spacecraft or reducing the time for intercontinental travel to just a few hours," said Matt Folk, CEO and president of the Purdue for Life Foundation. "We are grateful to the Indiana Congressional delegation that has supported



AAE Professor Steven Schneider's experience in designing, developing and building Purdue's Boeing/AFOSR Mach 6 Quiet Tunnel is a big reason the Air Force Research Lab approached Purdue with the task of designing and building the new quiet tunnel.

JOHN UNDERWOOD

Purdue's efforts in hypersonic research over the past several appropriation cycles and continues to help build this strength statewide.

"Like so many of the outstanding research facilities at Purdue, naming gifts and other financial support from our friends will ensure that the Hypersonics and Applied Research Facility is world class from the first day it opens and into the future."

MACH 8 QUIET TUNNEL

After the Cold War, when financial support for hypersonic research was nearly non-existent, AAE Professor Steven Schneider never stopped studying high-speed laminar-turbulent transition. In the early 1990s, he chose to persistently pursue a difficult and challenging idea: Measurements of hypersonic instability and transition in a newly developed low-noise "quiet" wind tunnel.

He designed, developed and built Purdue's Mach 6 quiet tunnel, funded by the Air Force Office of Scientific Research, the Ballistic Missile Defense Organization and The Boeing Company, and even though it took five years before it was operational as a quiet tunnel at high Reynolds numbers, his determination paid dividends. Then and now.

The Mach 6 tunnel still is currently one of only two working Mach 6 quiet tunnels in the country, more than 15 years after it started operating at quiet conditions.

So it's no surprise when the Air Force Research Laboratory was looking for someone to develop a Mach 8 quiet tunnel, it approached Purdue and Schneider. By summer 2019, Purdue was awarded two contracts totaling almost $10 million to design and build it.

"I think my credibility within the Department of Defense and the work that's been done in quiet tunnels over the last three or four decades, since before I started doing it, has all contributed to the Congress and the Defense Department seeing the value in trying to build a newer and better such facility at Purdue," Schneider said.

"I started working on quiet tunnels in 1990. I spent years learning from NASA Langley, who had spent two decades previous to that working on them. I'm thankful for the opportunity to try to build another one, and I'm also looking for young faculty who are interested in picking up that baton as I need to start passing it to somebody younger who's going to be around for longer."

To that end, Schneider approached one of his former graduate students, Brandon Chynoweth, and asked if Chynoweth would be willing to take on the project of designing, developing and running the new tunnel.

Chynoweth (MSAAE '15, PhD AAE '18) was stunned. And excited.

"I've always wanted to design a wind tunnel. Usually you're retrofitting old tunnels. You don't get to design a new facility often, so I hopped at the opportunity," said Chynoweth, co-principal investigator with Schneider on the project. "To have Steve as the senior advisor on the project and be able to build basically what he had always hoped to build during his career was an opportunity I couldn't pass up."

Since, Chynoweth has worked closely with Schneider, calling the long-tenured professor a valued mentor and world expert. They've been able to leverage Schneider's experience of planning, designing, constructing and using the Mach 6, as he shared a list of things that might cause the new tunnel not to achieve quiet flow.

It's not an identical process — the Mach 8 development is more challenging because it operates at higher temperatures, above 800 degrees F. That produces a new problem: The nozzle is polished like a mirror, but at elevated temperatures, metals begin to oxidize. That surface oxidation, or corrosion, leaves a roughness that could cause flow to be turbulent on the nozzle wall, completely inhibiting quiet flow operation.

It has been a difficult task figuring out which metals don't corrode at high temperatures, Chynoweth said.

By 2023, the 65,000-square-foot, $41-million Hypersonics and Applied Research Facility is expected to be completed. It'll house the Hypersonic Pulse reflected shock/expansion tunnel (HYPULSE), donated by Northrop Grumman Corporation, and a newly developed and constructed Mach 8 quiet tunnel, which will be the first of its kind capable of collecting data at speeds greater than Mach 6.

"It's exciting it's getting built, but we know that even though it's all put together, that's the end of construction but just the beginning of achieving a quiet flow environment," Chynoweth said. "We're trying to do as much research as we can to build this test facility for the Department of Defense and its contractors to use and also for some basic research work as well. But it's a research project. There are challenges. There are unknowns. There are risks we can only buy down so far before we have to make a really tough choice.

"So it's a juxtaposition of being excited *and* up at night thinking, 'What is going to be the one thing that stops this?' Because it only takes one nick in the nozzle or one thing going wrong for it to not work as a quiet tunnel."

Schneider knew the detail-oriented Chynoweth fit the mold of tackling such a task by seeing him build relationships with customers during a number of tests in the Mach 6 tunnel over the last several years. He implicitly trusts the now-research assistant professor with the monumental task of getting the tunnel not only operational but running quietly smoothly.

That "quiet" element is key, and it's what makes Purdue's tunnels special.

Quiet wind tunnels more closely simulate flight and provide more accurate data than conventional hypersonic wind tunnels. A better understanding of when and how airflow over a surface changes from smooth, or laminar, to turbulent is essential in the successful design of expendable and reusable hypersonic vehicles. Collecting data at higher Mach numbers is critical to extending the understanding of flow physics, especially heat transfer and flight control effectiveness, as DOD programs continue working to fly faster and farther.

The Mach 8 quiet tunnel will provide measurements that can be used to better inform computational simulations. Schneider, Chynoweth and Jewell, who will oversee basic research work in the tunnel, expect customers to be steady and consistent once the tunnel is operational, which Chynoweth said could happen as soon as late 2023. From there, it could be two to five years until it's quiet at a substantial Reynolds number.

"Getting quiet flow at high enough pressure that you can make meaningful measurements, that's the big thing," Chynoweth.

If quiet flow can be achieved, it'd be a game changer for Purdue, allowing measurements no one has ever seen. And they'd matter, Schneider said.

"If we can be successful, we will have made a substantial contribution to national defense," Schneider said. "That's a good thing for the national defense, which is also good for Purdue to be a national leader in something that's important to the country. It's good for the state of Indiana.

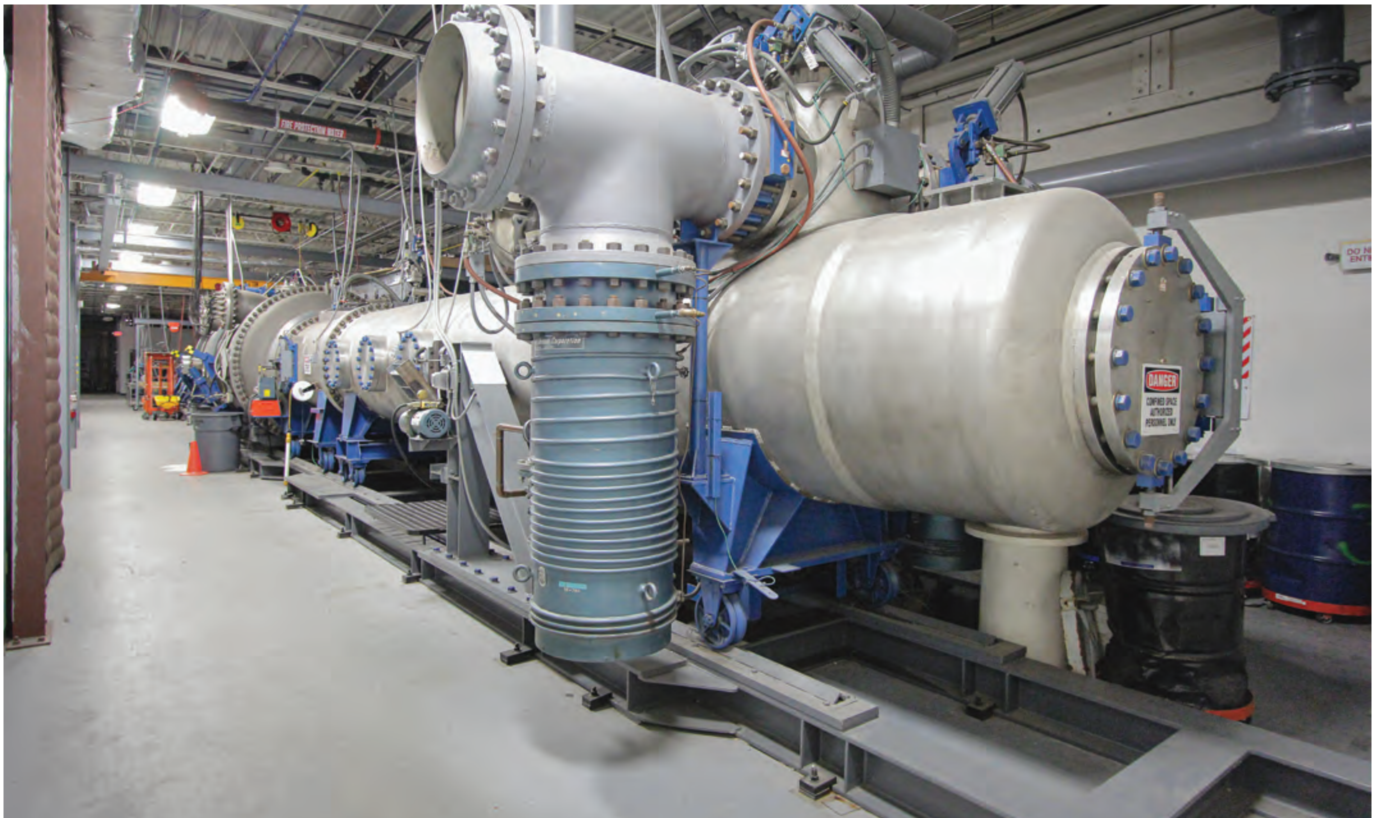
"If we can be successful, we can do things that have never been done before and make a contribution to defending freedom."

HYPULSE

Unlike the Mach 8 quiet wind tunnel that's being developed from scratch, HYPULSE should be operational more quickly. That's because the 150-foot-long tunnel, which was disassembled for the trip from New York to Indiana, already was a working tunnel.

The tunnel has been enhanced and expanded a couple of times since the 1960s, Jewell said, but there is more to do.

Purdue will upgrade much of the instrumentation, and the control mechanisms will be redone to modern standards so it



Unlike the Mach 8 quiet wind tunnel that's being developed from scratch, HYPULSE should be operational more quickly. That's because the 150-foot-long tunnel, which was disassembled for the trip from New York to Indiana, already was a working tunnel.

can be controlled primarily from a computer instead of physically having valves turned.

"I think toward the end of when the building is getting done, the bigger parts of HYPULSE can be moved in and assembled, probably at the same time," Jewell said. "I would expect we'll be able to run it within a few months of the building being completed, simply because all we have to do is put it together, really."

An important element in the new building will be the laser room next to HYPULSE, allowing cutting-edge high-speed optical measurements to be taken, Jewell said.

Once HYPULSE is installed and operational, Purdue will be only the second university in the U.S. to offer such a comprehensive hypersonic test capability.

HYPULSE will allow flight simulations at speeds ranging from Mach 5 to as high as Mach 40 and will be useful for testing by researchers from academia, industry and government. Collecting data at higher Mach numbers and temperatures is critical to extending the understanding of flow physics, especially heat transfer and flight control effectiveness.

Reflected shock/expansion tunnels like HYPULSE use shock waves to create a reservoir of high pressure, high-temperature gas — briefly reaching temperatures as high as 16,000 degrees F — that is then expanded through a nozzle at high speeds, reaching velocities of 15,000 mph or higher for very short periods of time, from a thousandth to a hundredth of a second.

The high-speed tests recreate high-speed flight scenarios, such as spacecraft re-entry or missile flight through the atmosphere, as well as replicate unique engine conditions for extremely high-speed propulsion.

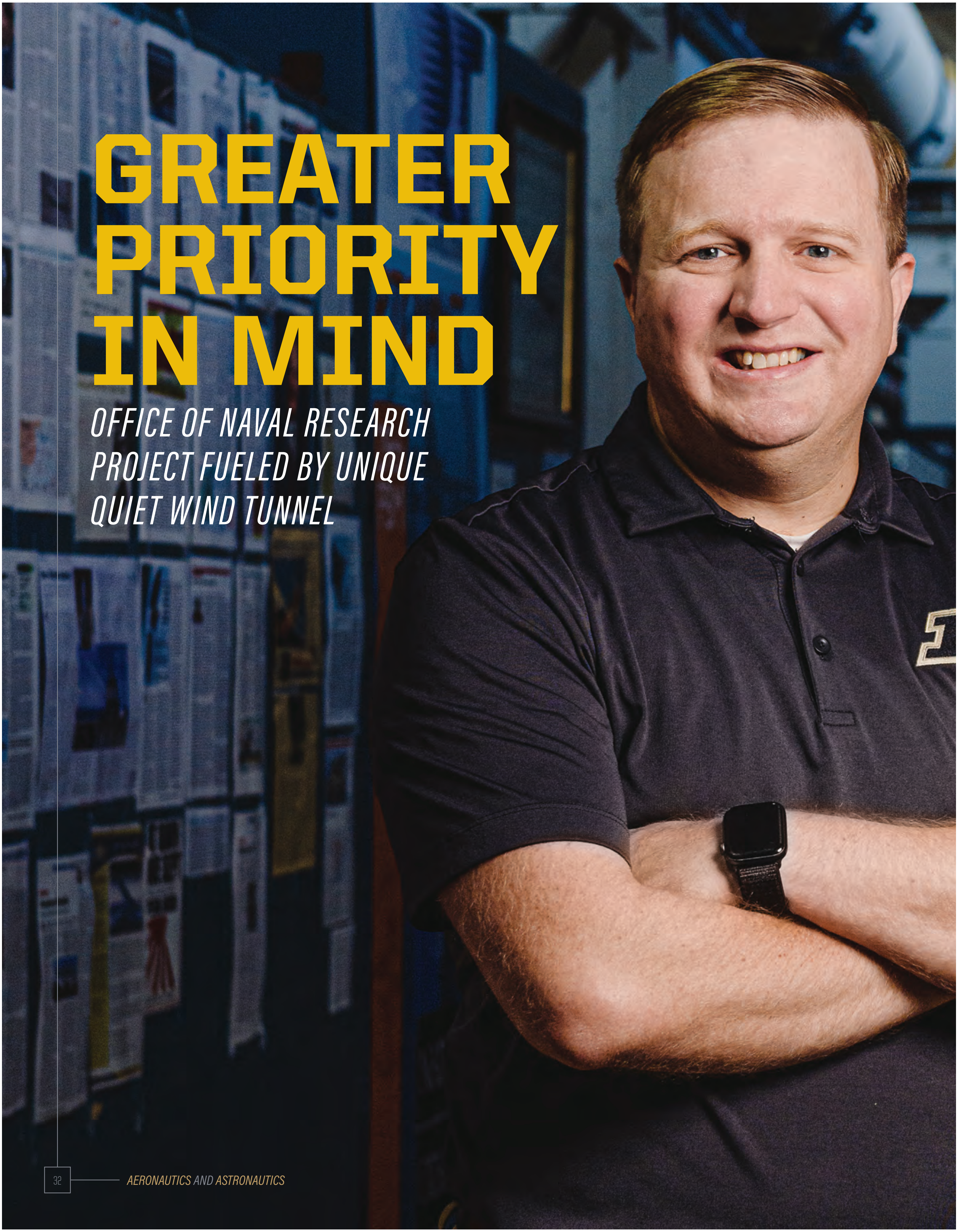
"With HYPULSE, we'll have access to higher Mach numbers, faster velocities and higher temperatures than we have previously been able to work with at Purdue," Jewell said. "This expands Purdue's hypersonics capabilities to everything short of actual flight tests. This will open up a whole new area of aerodynamic research for us."

Jewell will focus on aerodynamics testing programs in the facility, while AAE Associate Professor Carson Slabaugh will work with propulsion projects.

"Very few experimental facilities can replicate these conditions," Slabaugh said. "In the university environment, we can be very agile, working on different projects with government and with industry. We're researchers, keen to understand the fundamental flow physics at relevant flight conditions."

**Cleared for public release by the Air Force Research Lab, Case Number AFRL-2021-3046*

For information on naming rights for the Hypersonics and Applied Research Facility, contact Rita Baines, chief development officer, at rlbaines@purdueforlife.org or 765-494-9124).



GREATER PRIORITY IN MIND

OFFICE OF NAVAL RESEARCH PROJECT FUELED BY UNIQUE QUIET WIND TUNNEL

REBECCA McELHOE

For Joseph Jewell, this is personal.

When he applied for the highly competitive Young Investigators Program through the Office of Naval Research, he had his grandfather, Charles "Chuck" Jewell, in mind.

Chuck Jewell was a chief petty officer in the U.S. Navy, serving overseas in World War II in the Pacific theater and stateside during the Korean War. Nearly 70 years later, Chuck Jewell's successors still are putting their lives on the line for the United States, specifically naval units in the Pacific. Only in the last decade or so has the Department of Defense ramped up its funding of hypersonic research, after it largely dried up after the Cold War. The resurgence was a necessary response to adversaries' advancements in high-speed flight technology.

Novel research to solve the unique problems presented in hypersonic research are of national importance.

Enter Jewell, an assistant professor in AAE, with that greater priority in mind.

Jewell was selected in May 2021 to receive a three-year, $600,000 grant from the Office of Naval Research for "detailed investigation of hypersonic instability, breakdown and natural transition under quiet flow with simulated ablation-gas injection." The research could provide a relevant and highly useful approach to visualize hypersonic flow fields, as well as a promising measurement for high-enthalpy or ablative flows that naturally produce carbon monoxide among other carbon-containing molecules.

When vehicles travel at hypersonic speeds through the atmosphere — at least five times the speed of sound — they undergo a process called "ablation" where, at high temperatures and high speeds, material vaporizes and erodes from the surface of the vehicle. The erosion happens as a complicated interaction between the surface and the aerodynamics. Understanding how that process happens is important: When a vehicle runs out of material to ablate away, it fails.

Jewell's research seeks a better understanding of ablation to predict the effects of it.

Because a lot of the heat shields and outer structure materials are carbon-based — carbon fiber, carbon woven or impregnated carbon — one of the main gases that tends to be created during ablation is carbon monoxide (CO). Though Jewell can't make ablation happen in the Boeing/AFOSR Mach 6 Quiet Tunnel — the flow is too cold — he will use a technique to measure CO injected through the surface of the wind tunnel model to simulate the process. He initially read about the technique as an application of the combustion industry with engineers designing an automotive or other internal combustion engine. In that process, CO is generally an indicator of incomplete combustion. In a typical combustion process, that's happening at fairly high pressures. But Jewell noticed that particular technique for detecting CO actually worked much better at lower pressures.

In a hypersonic wind tunnel, there are extremely low pressures.

"In theory, at least, we should be able to make better use of this technique or get a better picture from this technique than the people who actually came up with it and applied it for the first time to these combustion-type burning processes, flames and so on," Jewell said. "Because our tunnel, like essentially all hypersonic wind tunnels, is low pressure in the free stream. That's by design because at high altitude, the air is low pressure also. So it all scales."

Jewell's group will plumb the inside of the wind tunnel model with pipes attached to it to a tank of gas and inject the gas at controlled rates. The team will document what they're doing and then take pictures of the process. Essentially, it will be looking at the effects of the gas injection on boundary layer stability downstream.

Purdue's Mach 6 Quiet Tunnel is uniquely well-suited for the research, as it is the largest operational tunnel in the world able to produce low-disturbance flow.

"It's a technique that's been used in flames and burning processes, but no one has used it in a wind tunnel of any kind, as far as I know, let alone a hypersonic wind tunnel," Jewell said. "That's what I think particularly interested the Navy program manager who decided to fund the work.

"It's really a project that couldn't be done in the same way anywhere else but Purdue. So that's why I thought it made a good choice. I'm always looking for things that we can do that no one else can do. This was one of them."

Jewell will collaborate with other Purdue researchers. Terrence Meyer, a professor in Mechanical Engineering with a courtesy appointment in AAE, and ME Research Associate Professor Mikhail Slipchenko will assist on the research that includes a pulse-burst laser, and AAE Professors Sally Bane and Carson Slabaugh are offering use of some their equipment, such as high-speed cameras.

ICYMI

TEACHING FELLOWSHIP PREPARES PHD STUDENTS FOR ACADEMIC CAREER

Instead of hosting office hours and addressing students on a one-on-one basis as a teaching assistant, Omanshu Thapliyal and Rolfe Power started fall 2021 standing in front of classrooms of as many as 40 AAE undergraduate students.

In a new role as AAE teaching fellows, Thapliyal and Power needed to make immediate adjustments.

Catering learning to one specific student wasn't an option in this environment. Now, their eyes had to constantly flicker across the room, intent on reading non-verbal cues, gauging whether students were understanding the material. Did they need to change the way they were teaching a concept? Did they need to pause and add more detail, solicit questions? Were they using vernacular consistent with the level of the students?

Each lecture was different and provided an opportunity to learn, to continuously improve, to spontaneously change a teaching method or quickly think of examples students could relate to.

"It has been fantastic," said Power, whose advisor is Kathleen Howell, the Hsu Lo Distinguished Professor of Aeronautics and Astronautics. "The students are inspiring me, and it has been a great joy to introduce the students to a field that I love.

"A key factor in my decision to continue into postgraduate studies was my desire to explore teaching as a career path. The teaching fellowship provides an opportunity to get real experience in front of a classroom of the best and brightest at one of the top engineering schools in the world. It simply is an experience that was too good not to pursue."

That is exactly the point of the fellowship, enabled by a generous donor in October 2019. AAE PhD students are paired with a faculty mentor and instruct a course with the intention that each small step made in the program will move fellows closer to taking the next giant leap in their career.

Applications are submitted to Karen Marais, associate head for undergraduate education, and the School's Curriculum Committee selects the fellows.

Marais, Martin Corless and Joseph Jewell were the mentors for fall 2021. They act as sounding boards, resources and sharers of teaching materials and teaching experiences.

It is an experience Marais cherishes.

"I enjoy mentoring," said Marais, who uses Microsoft Teams to connect with the teaching fellows and help answer any questions they might have. "We all shared things we've learned in our classes, tips and tricks. We all get value out of it, even those of us who have been teaching for a long time. From an associate head perspective, it helps me to make sure we're maintaining the quality of our teaching.

"There's a need for instructors, there's a need for quality instruction and there's a need to prepare graduate students for faculty careers. This program is a very conscious effort for us to provide teaching training while meeting a critical department need for quality instruction. It's a win-win situation for everyone."

Teaching fellows are assigned to high-enrollment undergraduate courses with multiple sections. In fall 2021, AAE203, AAE230 and AAE251 had teaching fellows. Power handled 203, Aeromechanics I, under mentor Corless; Thapliyal was assigned Intro to Aerospace Design (251), under Marais; and Nirajan Adhikari taught a section of 333, Fluid Dynamics, under Jewell's guidance. Each mentor is an expert in the particular discipline and has taught the course before.

The fellows are exposed to everything an AAE faculty member would be in their teaching roles. Fellows work with the teaching mentor to prepare assignments, quizzes and exams. They actively plan how to present that material, rather than just reacting to students' questions about what they heard in class, like in a TA role. They do the same level and type of grading as the teaching mentor. They actually instruct courses. They carry the emotional weight of being invested in the students' success.

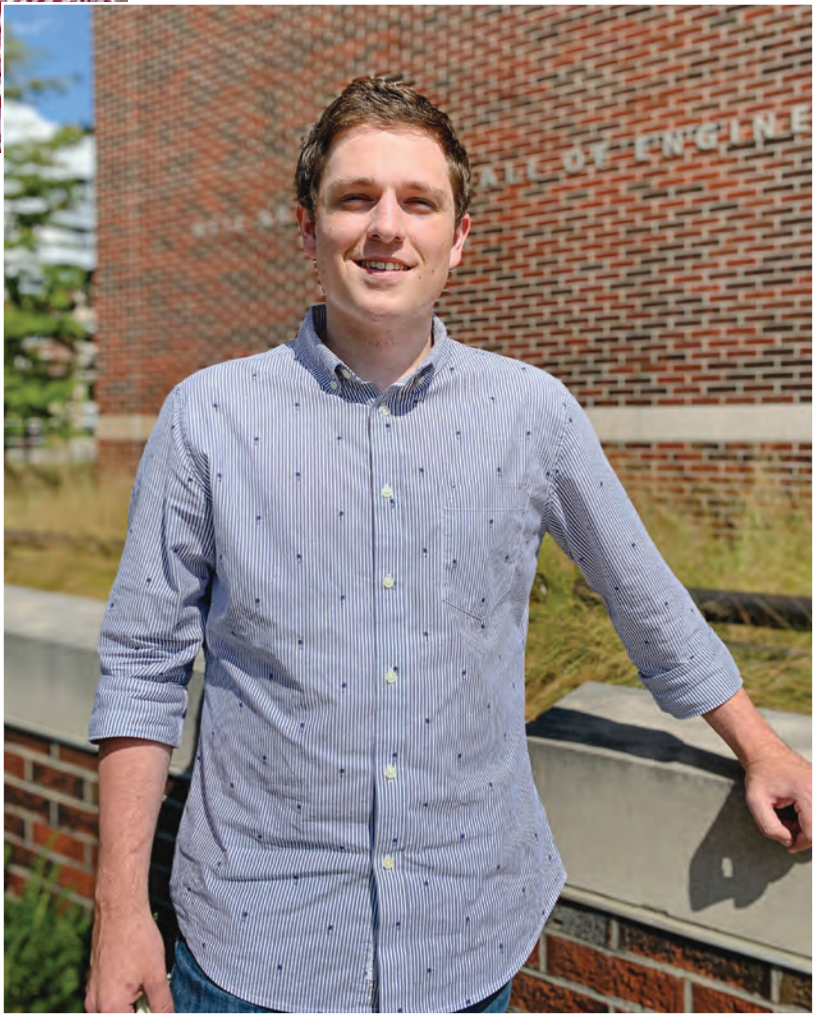
And then they get instant feedback on all of it from the faculty mentor and students they're teaching, which helps the fellows improve and, even, define their teaching styles.

"Being an instructor allows me to interact more with students, design my own course material to a certain degree, and invests in me the responsibility of my own section. It is a great way for me to try out to be an instructor as a PhD student," said Thapliyal, whose previous TA experience included 251. "While being a teaching assistant allows us to learn about how the course works, the increased autonomy and responsibility invested in me by the University is a great learning experience."

Interested in supporting the AAE Teaching Fellowship Program? Please contact Rita Baines, chief development officer, at rlbaines@purdueforlife.org or 765-494-9124).

"BEING AN INSTRUCTOR ALLOWS ME TO INTERACT MORE WITH STUDENTS, DESIGN MY OWN COURSE MATERIAL TO A CERTAIN DEGREE, AND INVESTS IN ME THE RESPONSIBILITY OF MY OWN SECTION. IT IS A GREAT WAY FOR ME TO TRY OUT TO BE AN INSTRUCTOR AS A PHD STUDENT."

- OMANSHU THAPLIYAL



"A KEY FACTOR IN MY DECISION TO CONTINUE INTO POSTGRADUATE STUDIES WAS MY DESIRE TO EXPLORE TEACHING AS A CAREER PATH. THE TEACHING FELLOWSHIP PROVIDES AN OPPORTUNITY TO GET REAL EXPERIENCE IN FRONT OF A CLASSROOM OF THE BEST AND BRIGHTEST AT ONE OF THE TOP ENGINEERING SCHOOLS IN THE WORLD."

- ROLFE POWER

ICYMI

STUDENT NEWS

NATIONAL SCIENCE FOUNDATION GRADUATE RESEARCH FELLOWSHIP PROGRAM

Two graduate students in AAE were selected for the prestigious National Science Foundation Graduate Research Fellowship Program (GRFP). Derrick Charley and Ann Marie Karis received the oldest graduate fellowship of its kind.

The five-year fellowship period provides three years of financial support, including an annual stipend of $34,000 and a $12,000 cost-of-education allowance for tuition and fees. The fellowship also provides access to opportunities for professional development.

The GRFP will support the research Karis is doing as part of her graduate research assistantship, a collaborative project that spans several institutions. The Virtual Super-Resolution Optics with Reconfigurable Swarms mission is composed of two CubeSats flying in a configuration with 40 meters between them. The goal of the mission is to investigate energy-release sites in the solar corona by producing images. Karis, whose advisor is Professor Alina Alexeenko, has been modeling CubeSat plume interactions and aerodynamic drag using the Direct Simulation Monte Carlo code, SPARTA.

BILSLAND DISSERTATION FELLOWSHIP

Kenza Boudad, Suman Chakraborty and Saikiran Gopalakrishnan were awarded the Bilsland Dissertation Fellowship. Each recipient received a base salary of $20,000, a supplemental scholarship of $10,000 and a graduate tuition remission for up to two semesters and one summer session.

Boudad, whose advisor is Kathleen Howell, the Hsu Lo Distinguished Professor of Aeronautics and Astronautics, focuses on the development of a framework for trajectory design between the lunar region, where the upcoming NASA's Gateway is planned to be located, and heliocentric space, which includes destinations such as Sun-Earth orbits, various asteroids, and Mars. Boudad's research leverages the Bicircular Restricted Four-Body Problem, a multibody dynamical model that considers the gravitational influences of the Earth, the moon and the sun. Using this framework, researchers are able to compute end-to-end transfers between Gateway's orbit and various heliocentric destinations.

Suman Chakraborty's research deals with the study of high-pressure combustion systems and phase behavior. Chakraborty, in Professor Li Qiao's research group, has used Molecular Dynamics (MD) as a tool to study fluid behavior under extremely high pressure and temperature conditions, phase change dynamics and the effect of multicomponent system composition on the transition behavior from sub-to-supercritical regime. He also has used data-driven learning methods to predict the vapor-liquid equilibrium behavior of binary systems like n-alkane/nitrogen.

Gopalakrishnan's research is broadly focused on developing and demonstrating a comprehensive framework — model-based feature information network or MFIN — to leverage the use of next generation digital twin technology, which is crucial for efficiently designing and manufacturing mission critical aerospace components in the future. The introduction of the MFIN framework facilitates access to dynamically evolving lifecycle data applicable to a component or a product for use within physics-based predictive models, thereby improving the precision in downstream engineering analysis and enabling more informed decision making. His advisor is Michael Sangid, the Elmer F. Bruhn Professor of Aeronautics and Astronautics.

PATTI GRACE SMITH FELLOWSHIP

Zion Moss was among 43 Black undergraduates selected for the inaugural fellowship, created in 2020 to "combat the longstanding and well-quantified under-representation of Black and African-American employees in the U.S. aerospace workforce." The first fellowship class consisted of first- or second-year students in bachelor's or associate's degree programs across the country.

Moss secured his first aerospace internship with the fellowship, a 12-week paid gig with SpaceX. He also was paired with two mentors in the industry and received a cash grant toward professional or school expenses.

MATTHEW ISAKOWITZ FELLOWSHIP

Maor Gozalzani was one of 30 students chosen in the fellowship program's Class of 2021. Since the fellowship's inception in 2018, Gozalzani is the fourth AAE student selected for the program that provides college juniors, seniors and graduate students with a paid summer internship and mentor at commercial spaceflight companies.

He had a 12-week internship at Virgin Orbit and was paired with an industry mentor.

Full-length stories can be found on AAE's website, purdue.edu/AAE/spotlights

ALUMNI NEWS

ICYMI

GAMBARO, SKEEN SELECTED AS DEA

Ernest "Ernie" Gambaro (BSAAE '60, MSAAE '61) and Tanya Skeen (BSAAE '90) were honored as Distinguished Engineering Alumni, an honor presented to men and women who have distinguished themselves in any field in ways that reflect favorably on Purdue University, the engineering profession or society in general.

During a virtual ceremony in February 2021, Gambaro was recognized for his "forward-thinking approach to enabling client access to computer mainframes that transformed a computer time share into the world's largest provider of secure data network services to large and mid-size multinationals that provide sales and customer support in over 80 countries."

Skeen was honored for her "exemplary management of complex systems bringing together the United States Armed Forces, consisting of the Air Force, Marine Corps and Navy, as well as eight allied nations to implement affordable and sustainable fifth-generation strike aircraft."

ERNIE GAMBARO

TANYA SKEEN

The Outstanding Aerospace Engineer Class of 2021 (from left): Daniel Radocaj, Travis Langster, Joseph Cassady, Kevin Metrocavage, Frank Tse and Timothy O'Brien. Not pictured: Audrey Powers.

OUTSTANDING AEROSPACE ENGINEER AWARDS

The seven-member Outstanding Aerospace Engineer Class of 2021 was honored during an in-person ceremony in October 2021 at Shively Pavilion.

The group included Joseph Cassady (BSAAE '81, MSAAE '83), Travis Langster (BSAAE '94), Kevin Metrocavage (BSAAE '96), Timothy O'Brien (BSAAE '88), Audrey Powers (BSAAE '99), Daniel Radocaj (BSAAE '00, MSAAE '01) and Frank Tse (MSAAE '82).

AAE honored its OAE Class of 2020 in a virtual ceremony held in April 2021, after the initial banquet was postponed due to COVID-19. The class included Douglas Adams, Christopher Clark, Darin DiTommaso, Douglas Joyce, Yen Matsutomi, Loral O'Hara, David Schmidt, Steve Slijepcevic and Rhonda Walthall.

OAE PHOTO; DAVE MASON

Full-length stories can be found on AAE's website, purdue.edu/AAE/spotlights

ICYMI

BANDLA NAMED "YOUNG ENGINEERING ALUMNI AWARD" WINNER

Sirisha Bandla may describe her career path as "unconventional," but her first decade in the aerospace industry has been a rewarding and impressive one nonetheless.

From her first engineering job designing components for advanced aircraft at L-3 Communications Integrated Systems, to an unexpected move into space policy with the Commercial Spaceflight Federation, to her springboard to executive levels at Virgin Galactic.

Each small step along Bandla's journey played a role in producing her ultimate career goals.

And she was recognized for all of it in September.

Bandla (BSAAE '11) was honored with the "Young Engineering Alumni Award" at the Purdue Engineering Alumni Association dinner and awards presentation. She is the fifth AAE alum to be selected for the award, first presented in 2012.

"It has a really big meaning to me because Purdue was such a changing point in my trajectory in my career," Bandla said, "so to be honored by the College is very special."

Bandla was chosen by the EAA board before July 2021, which is significant because that's when arguably the true "giant leap" of her career occurred. As a mission specialist for Virgin Galactic's suborbital flight, Bandla became part of Purdue's Cradle of Astronauts. (See inside cover.) But, as underscored by the award, Bandla was considerably accomplished before becoming a commercial astronaut.

After graduating from Purdue, Bandla secured a job as an engineer at L-3 Communications Integrated Systems. But Steven Collicott had other ideas.

The AAE professor who'd connected with Bandla during his Zero-Gravity Flight Experiment course suggested Bandla join the Commercial Spaceflight Federation, a trade organization in Washington D.C. that educates and advocates in support of members of the "new space" generation of orbital and suborbital rocket companies. She took the opportunity in a field that "I had no idea what I was doing originally," she said with a laugh, figuring in a few years she'd get back into conventional engineering.

She didn't.

She quickly found she fit at CSF and had a passion for space policy. Her AAE curriculum gave her a solid foundation in both technical expertise and communication. The former was especially a huge asset, as she was able to understand and communicate complex issues to both the public and policy makers.

"I loved that I was in a position to create a lot of change and create a lot of change quickly and to help grow this industry that I believed in and supported so much," she said. "I really wanted to be part of what made it successful."

Perhaps the most important piece of Bandla's time at CSF was her lengthy labors supporting the Commercial Space Launch Competitiveness Act that became federal law in 2015. It was one of the first bills she advocated for from start to finish, and she worked with CSF member companies to make sure all the priorities of the industry were reflected in the legislation. One of the big pieces of the legislation was extending the learning period for commercial suborbital companies to allow them to make systems safer for human spaceflight, allowing companies to be innovative in how they designed their human spaceflight system regulations.

Bandla has the first page of the legislation framed and hanging in her office.

"That really helped spur the growth of our industry, in a time when launches were becoming more frequent, and especially for the start of commercial human spaceflight," she said. "It was a celebration for everyone who worked on it, both government and industry. It also was the year I transitioned to Virgin Galactic. It was perfect timing."

After starting at Virgin Galactic in 2015, she built up a team that grew the company's presence in D.C and its research portfolio through work with the science and technology community. She secured the latter responsibility, in part, because of her AAE experience.

As part of Collicott's 418 class in 2010, Bandla was selected to lead a student team that designed, built and tested a zero-gravity flight experiment. The unique payload was selected by NASA, and the group tested it on NASA's KC-135A aircraft that simulates zero gravity.

"I was able to fly our research payload on parabolic flights, which was really the catalyst for me getting the research portfolio, which is such an important and fulfilling part of my job right now," she said.

As vice president for government affairs and research operations at Virgin Galactic, Bandla leads all of the company's interactions with local, state and federal governments and is involved in their work with the FAA, NASA science research and technology advancement, including the start of human-tended suborbital research, among other things.

"My trajectory was not a straight line that I intended to reaching my goal. There were a lot of curves, a lot of turns, but eventually I got to work for the company I really wanted to work for," she said. "The aerospace engineering degree I got and all the schoolwork and skills and knowledge that I was able to get through my five years at Purdue prepped me for all of these different opportunities that came my way. Some weren't engineering. At the moment, I'm not in a traditional engineering role. But everything I did at Purdue prepared me to be successful in every role I've been in."

"THE AEROSPACE ENGINEERING DEGREE I GOT AND ALL THE SCHOOLWORK AND SKILLS AND KNOWLEDGE THAT I WAS ABLE TO GET THROUGH MY FIVE YEARS AT PURDUE PREPPED ME FOR ALL OF THESE DIFFERENT OPPORTUNITIES THAT CAME MY WAY.

- SIRISHA BANDLA

Bandla was the leader of an AAE undergraduate team selected by NASA for weightless flight testing in parabolic aircraft flight in June 2011, an experience she said was the catalyst for getting the research portfolio at Virgin Galactic.

FROM TOP: VIRGIN GALACTIC; NASA JSC

ICYMI

FACULTY NEWS

HEISTER HONORED BY AIAA

Stephen Heister, the Raisbeck Engineering Distinguished Professor for Engineering and Technology Integration, was selected as the 2021 American Institute Aeronautics and Astronautics Wyld Propulsion Award winner. The award is presented for outstanding achievement in the development or application of rocket propulsion systems.

Heister was recognized during a virtual AIAA Propulsion and Energy Forum Awards Ceremony in August for "continuous leadership in advancing rocket propulsion engineering through state-of-the-art computational and experimental research and decades of mentorship of students."

"It is humbling to be recognized by peers in the rocket propulsion community with this honor," Heister said.

Though he came to Purdue with a focus in solid rocket propulsion, Heister's interests branched into hybrid and liquid propellant rockets through his 31-year career at the University. He and his students have published experimental and theoretical modeling results in all aspects of chemical rocket propulsion and he is co-holder of a patent for a high-strength solid rocket propellant formulation.

Since 2014, a major focus of his research has been related to rotating detonation engines (RDEs). The RDE is a device that exploits continuous detonative combustion in a thin annular channel and has the potential to advance aerospace propulsion performance significantly.

Heister was named an AIAA Fellow in 2013.

The Propulsion Award and the James H. Wyld Memorial Award, honoring the developer of the regeneratively cooled rocket engine, were combined in 1964 to become the James H. Wyld Propulsion Award. It was renamed the Wyld Propulsion Award in 1975. Two other AAE professors have received the AIAA honor, Maurice Zucrow (1966) and John Robert Osborn (1995).

MARAIS EARNS WIA AWARD

Karen Marais, associate head for undergraduate education, was selected to receive the 2021 Aerospace Educator Award by Women in Aerospace (WIA).

Marais, who joined the AAE faculty in 2009, was recognized for "excellent leadership and sustained dedication to aerospace education" and "tenacious advocacy for girls and young women in aerospace," a release from WIA said.

Thirty other women have received the award, first presented in 1990. AAE alumna Seetha Raghavan, a professor at the University of Central Florida, was the most recent recipient in 2019.

"I am truly honored to be joining a list of such distinguished women, including some who personally inspired me on my own journey through graduate school," Marais said.

Full-length stories can be found on AAE's website, purdue.edu/AAE/spotlights

THIRD MURPHY AWARD WINNER FOR AAE

Marais was one of five professors selected to receive the 2021 Charles B. Murphy Outstanding Teaching Award, Purdue University's top undergraduate teaching honor.

She was only the third AAE professor to win the award, joining Kathleen Howell (2013-14) and Severino Koh (1966-76). The honor, accompanied by a $10,000 cash award and induction into Purdue's Teaching Academy, is given to an associate or full professor who demonstrates superior ability in communicating material to stimulate students' desire to master the material and whose teaching responsibility doesn't stop at the classroom door.

"I put an enormous amount of effort into my teaching, and having it be recognized in this public way is really a great feeling," Marais said. "Students sometimes tell me in person that I've meant something to them, but having it acknowledged in this way, there's something special about that."

NEW FACULTY FOR 2021

In fall 2021, Leifur Leifsson joined AAE as an associate professor in structures and materials, and David Arnas joined AAE as an assistant professor in the astrodynamics and space applications group.

Leifsson's research focuses on computational modeling, optimization and uncertainty quantification of engineered systems. Specifically, Leifsson creates new and efficient surrogate-based approaches using novel multifidelity methods and machine learning.

Arnas started doing research in astrodynamics, satellite constellation design and applied mathematics. He has continued to diversify his research with work on perturbation theory, mission analysis and algorithm generation for different applications including star-trackers, database searching or the solution of differential equations.

FACULTY PROMOTIONS

Five faculty members in AAE had promotions approved by Purdue University's Board of Trustees in April 2021 and were effective August 2021.

Michael Sangid and Dengfeng Sun were promoted to full professor. Shaoshuai Mou, Alexey Shashurin and Carson Slabaugh were promoted to associate professor with tenure.

Two Mechanical Engineering professors who have courtesy appointments in AAE also had promotions approved: Fabio Semperlotti to professor and Andres Arrieta to associate professor.

IN MEMORIAM

1940s
Donald H. Heile (BSAE '45)
Maurice M. Hardy (BSAE '48)
Seth E. Burgess (BSAE '49)
Walter C. Boldt (BSAE '49)
Bob Newill (BSAE '49)

1950s
Ralph L. Gilbert (BSAE '50)
John A. Thelander (BSAE '50)
Harvey G. McComb (MSAE '50)
Peter H. VanGorp (BSAE '51)
Marjory J. Barriage (BSAE '51)
Ralph Tate (BSAE '52)
John P. Pedjoe (BSAE '53)
Philip P. Truax (BSAE '54, MSAE '55)
Hans K. Karrenberg (BSAE '54)
Donald C. Fritz (BSAE '55)
William J. Schatz (BSAE '56)
Richard L. Bower (BSAE '57)
William R. Bolles (BSAE '57)
James F. Rittenhouse (BSAE '57)
Joseph E. Shackford (BSAE '58)
Charles F. Patterson (BSAE '58)
Richard A. Powell (BSAE '59)
Max E. Hillsamer (BSAE '59)

1960s
Renny S. Norman (BSAE '60)
Daniel F. Stubbs (BSAE '60)
Stottler K. Starr (BSAE '61)
Ronald R. Clark (BSAE '62)
A. Keith Crozier (BSAE '62)
Bruce W. Landeck (BSAE '63)
Barbara B. Moore (BSAE '63)
Lee J. Hesler (BSAE '64, MSAE '66)
Richard V. Beard (BSAE '64, MSAE '65)
Dick S. Oberg (MSAE '64)
Benny J. Lanterman (BSAE '65)

1970s
Larry L. Roth (BSAE '70)
Terry G. Christiansen (BSAE '71)
John S. Hsu (MSAAE '78)

1980s
Gary E. Arnold (BSAAE '81)
Rigoberto Perez (BSAAE '81, MSAAE '83, PhD AAE '86)
Jon J. Shaw (BSAAE '84)
Mark E. Behnke (BSAAE '84)

1990s
Thomas V. Miller (BSAAE '90)

2000s
Kyle Runkle (BSAAE '20)

PURDUE UNIVERSITY
School of Aeronautics and Astronautics

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