AEROGRAM

2023/2024

PURDUE UNIVERSITY SCHOOL OF AERONAUTICS AND ASTRONAUTICS

A PROPULSION REVOLUTION

Purdue researchers are leading in study and design of liquid-cooled 3D-printed rotating detonation engines, which could transform spacecraft and hypersonic vehicles

PAGE 14

LORAL O'HARA LAUNCHES ON HER FIRST SPACE MISSION

The crowd grew in the Armstrong Hall atrium on the morning of September 15 as Loral O'Hara's launch time approached. In addition to faculty, staff and students, Purdue's visiting Engineering Advisory Council took a break from the day's activities to watch O'Hara (MSAAE '09) blast off on Soyuz MS-24 for her six-month mission to the International Space Station.

It was a tense eight minutes for AAE Professor William Anderson, O'Hara's friend and former faculty advisor. After the rocket stages had finished, Anderson was visibly relieved — all smiles and cheer. O'Hara took her first spacewalk with on November 1 with Expedition 70 crewmate Jasmin Moghbeli. It was only the fourth all-female spacewalk in history.

Read about O'Hara and her path to NASA astronaut: Search for "Loral" at stories.purdue.edu.

NASA

NASA

PURDUE UNIVERSITY PHOTO/ANDREW SVAPRAKSAM

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ON THE COVER: Purdue's early start, unique capabilities and top level expertise positioned Boilermakers at the forefront of rotating detonation engines.

PURDUE UNIVERSITY PHOTO/ADRIAN MARTINEZ

PURDUE UNIVERSITY | School of Aeronautics and Astronautics

Purdue University is an equal access/equal opportunity university

IN THIS ISSUE:

LETTER FROM THE HEAD

Dear alumni, friends, students, staff and faculty,

It is no secret that enrollment at the Purdue School of Aeronautics and Astronautics has been growing at a very strong pace. In 2023, data from the Integrated Postsecondary Education Data System showed that we now grant more degrees in aerospace engineering than anyone else in the U.S. Our graduates represented 5.3% of all degrees in our field for the most recent recorded year.

We reached this landmark while pursuing the high quality of our education. *U.S. News and World Report* announced that Purdue's AAE undergraduate program had moved up by two spots: We are now No. 3 in the country for 2024. This is the highest spot AAE has held in the publication's 23-year history tracking aerospace engineering.

In addition, the ShanghaiRanking Global Ranking of Academic Subjects places our program tenth in the world for aerospace engineering.

This work is not easy. Our dedicated faculty and staff, plus our recent investments in additional instructors, are responsible for these remarkable parallel recognitions.

As our graduate count doubled over the last decade, to 317 bachelor's and 212 graduate degrees in the 2022-2023 academic year, our faculty have worked hard to maintain our world-class educational rank while pursuing cutting-edge research. We also hired 14 professors, professors of engineering practice and lecturers since 2020, 10 of those in the last 18 months.

We are continuing to improve our teaching and learning spaces, too. We expanded instructional labs this year (see page 46), giving students more hands-on time with equipment that physically demonstrates the phenomenon covered in lecture courses. At the time of this letter, we have leased additional space that clubs can use to build aircraft, rockets and satellites, many in preparation for national engineering competitions. This "AAE Maker Space" is necessary to support these co-curricular activities.

All of this is crucial to what we do. Our graduates are in high demand due to the unparalleled, hands-on experiences they get here, and the instruction they get from world-renowned faculty.

PURDUE UNIVERSITY PHOTO/JOHN UNDERWOOD

They engage in a huge range of activities, like going on Mars simulations (see page 4), flying a 14-foot-wingspan aircraft of their design with computer vision and autonomous navigation (see page 14), showing their grit with liquid-fueled rockets (see *Aerogram* 2022) and conducting important research on space domain awareness (see pages 5 and 13). Our alumni design spacecraft (see page 6) and become astronauts themselves (see previous page).

To take full advantage of our growth, we are also developing a strategic plan, with support from our Industrial Advisory Council and input from all AAE faculty and staff. To me, that is what being an engineer is all about. We love what we do, and we are always looking for ways to do it better.

I believe, as we continue investing in our faculty, students and staff, we can be the biggest as well as the best. I am certain that we will have more to celebrate in the coming year.

Boiler up!

Bill

William A. Crossley
Uhrig & Vournas Head of Aeronautics and Astronautics

AERONAUTICS AND ASTRONAUTICS BY THE

NUMBERS

RANKED 3RD
BEST UNDERGRADUATE AEROSPACE/ AERONAUTICAL/ ASTRONAUTICAL ENGINEERING
U.S. News and World Report (2024)

RANKED 6TH
BEST GRADUATE AEROSPACE/ AERONAUTICAL/ ASTRONAUTICAL ENGINEERING
U.S. News and World Report (2024)

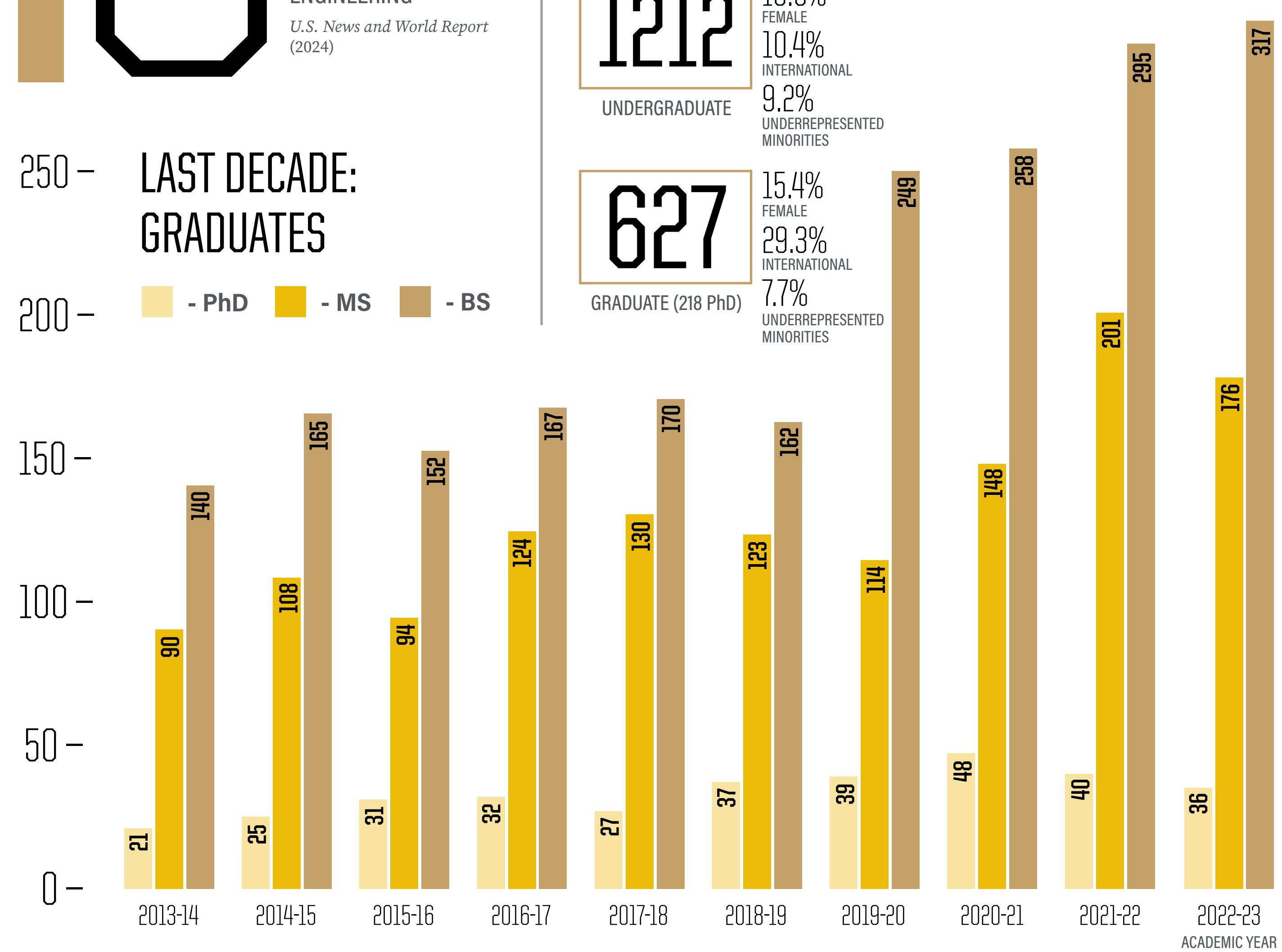
THE FACULTY (FALL 2023)

- 45 TENURED/TENURE-TRACK FACULTY
- 30 FULL PROFESSORS
- 11 ASSOCIATE PROFESSORS
- 4 ASSISTANT PROFESSORS
- 1 PROFESSORS OF PRACTICE
- 3 LECTURERS
- 2 RESEARCH FACULTY
- 3 VISITING ASSISTANT PROFESSORS
- 16 COURTESY FACULTY

THE STUDENTS (2023 FALL ENROLLMENT)

1212 UNDERGRADUATE
18.6% FEMALE
10.4% INTERNATIONAL
9.2% UNDERREPRESENTED MINORITIES

627 GRADUATE (218 PhD)
15.4% FEMALE
29.3% INTERNATIONAL
7.7% UNDERREPRESENTED MINORITIES



STUDENT NEWS

KSHITIJ MALL, AAE STUDENT

Students expedition to Utah as Mars analog astronauts

A team of Purdue students went on a two-week mission to the Mars Desert Research Station in January 2023, simulating the experiences of crew life on a research station on the Red Planet. A first-person account by AAE student Kenneth Pritchard was posted to the The Persistent Pursuit — Visit stories.purdue.edu and search for "MDRS." Two new crews are headed to MDRS for separate missions in December 2023.

AAE grad students receive significant research grants and fellowships from NASA, DOD

CHOUDARI

SUBRAMANYAN

HOWERTON

ROBINSON

Through the Future Investigators in NASA Earth and Space Science and Technology (FINESST) program, Siddharth Subramanyam and Archana Choudhari will both be assessing if Signals of Opportunity (SoOp) methods can be used to take measurements on Earth's surface. Their principal investigator (PI), Professor Jim Garrison, is a pioneer in this field.

Choudhari will look at root-zone soil moisture levels, which can provide warning of flood or drought. Subramanyam will explore techniques and methods of orbit determination of SoOp sources, that would enable a future SoOp altimetry mission.

Layton Howerton and Liam Robinson received two of the 165 National Defense Science and Engineering Graduate (NDSEG) fellowship awards. Robinson is continuing the Space Domain Awareness study he began as an undergraduate under Carolin Frueh, the Harold DeGroff Associate Professor of Aeronautics and Astronautics. He will further develop his reflectivity analysis algorithms to study satellites and orbital debris in greater detail. He also received fellowship offers from NASA and the National Science Foundation to pursue this work.

Howerton is using computer simulations to study how shapes can affect aerodynamic heating at supersonic and hypersonic speeds. His work focuses specifically on the shock wave and boundary layer interactions common at those speeds. Howerton is working under AAE Professors Jon Poggie and Greg Blaisdell.

PURDUE UNIVERSITY PHOTO/JOHN UNDERWOOD

3+2 dual-degree partnership provides opportunity for eager students

A partnership with Morgan State University, a historically Black institution, complements Purdue's efforts to provide opportunities for minority students in STEM fields. Don-Terry Veal Jr. is the first student to participate in this 3+2 program, which allows students to earn bachelor's degrees in distinct majors from both schools.

"When you don't see a lot of African Americans in the industry, especially in administrative positions, then it becomes a lot more daunting for you to see yourself in that position unless you already have some exposure to those who are pushing you," Veal says. "That's why I went to Morgan State — so I could experience more than just what is 'the norm.'"

Veal completed an engineering physics degree at Morgan State and is expected to receive his second bachelor's degree from Purdue in Spring 2024. Scholarships from various sources, including discretionary funding from the headship endowment established by William Uhrig and Anastasia Vournas, are helping to keep his Purdue costs as close as possible to his costs at Morgan State.

Veal is also planning to complete a one-year master's degree at Purdue through the combined BS/MS program, then pursue his PhD in aeronautics and astronautics.

The Purdue DRAGONfly team stands with advisor Steven Collicott (at right), professor of aeronautics and astronautics, behind an early foam mock-up of their autonomous data delivery vehicle. PURDUE UNIVERSITY PHOTO/ALAN CESAR

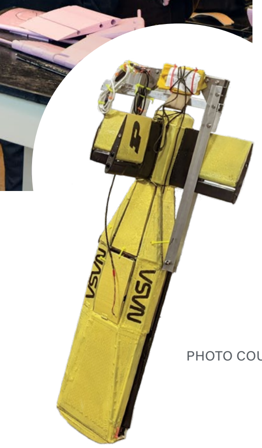


PHOTO COURTESY OF ALEXANDER TERRY

NASA to release student-built vehicle from 110k feet

A team of Purdue students are among the six finalists for NASA's Formulate, Lift, Observe And Testing; Data Recovery And Guided On-board Node Balloon Challenge. Each team designed a vehicle that could be released from a high-altitude balloon above 110,000 feet, which would then autonomously identify one of the designated landing spots and safely deliver its fragile payload of data storage drives. The finalists received NASA funding to build their designs and selected Purdue's among those to be released over Antarctica in late 2024.

Julie Kramer White (BSAAE 1990), director of engineering at NASA Johnson Space Center, is unflappable. After making space shuttle structural design a large portion of her career, she approached an all new vehicle — the Orion capsule — as its chief engineer. She has earned countless awards from NASA and Purdue and continues leading in engineering as NASA pushes human exploration deeper into space.

PURDUE UNIVERSITY PHOTO/REBECCA ROBIÑOS

A TITAN FROM THE MIDWEST

An alumna's career rocketed during the Shuttle era. She's now leading NASA engineering to the moon and beyond.

Texas sunlight, mercifully diffused by an overcast sky, fills Julie Kramer White's corner office at NASA's Johnson Space Center. It casts a glow on the moments and memories that cover the walls around her desk — icons representing decades.

Family photos with her daughter and husband. A framed print honoring her Old Masters presentation at Purdue in 2015. The day she met then-president Barack Obama, who later mentioned her by name in a speech on the Orion capsule's successful flight test: "When an American is the first to set foot [on Mars], they will have Julie and her team to thank."

Kramer White (BSAAE '90), director of engineering for all of JSC, beams as proudly in person as she does in each photo. The view from her standing desk extends for miles across Houston, out and past the sailboats on Clear Lake. But in her head and her work, she remains firmly grounded.

The large "Keep Calm and Carry On" print on her wall is autobiographical. Having overseen space shuttle structural design for a decade; having worked through both Challenger and Columbia accidents; having led design of NASA's newest crew capsule — Kramer White is steadfast.

Towering, despite her average stature. Welcoming, despite her extraordinary status.

Hoosier State credentials

Kramer White didn't want to be a doctor like her father. A broad public push in the '70s encouraged her to pursue STEM disciplines, and as a card-carrying member of the James Doohan International Fan Club — Scotty, from *Star Trek* — aerospace engineering was her field. But having grown up in the Indianapolis suburb of Zionsville, she was sometimes sheepish about being a Hoosier.

"I applied to a lot of different engineering schools around the United States, you know, MIT, Stanford. But honestly, what kept me in-state was the great economic value. Plus, I could go home on the weekends and steal all the food out of my parents' refrigerator," she smiles, now a knowing parent of her own college student.

But when she arrived at JSC for her co-op and explained to people that Purdue was in Indiana, she got an eye-opening surprise: "One of the senior engineers pulled me aside and said, 'We know where Purdue is … in fact, I couldn't get into Purdue … so stop saying that.'"

In 2014, Julie Kramer White cheered from Cape Canaveral Air Force Station as the Orion spacecraft successfully completed an uncrewed launch, orbit and splashdown. It was a proud moment for her as chief engineer on the spacecraft, which is designed to journey to the Moon and Mars.

NASA PHOTO/RADISLAV SINYAK

Launching a career at NASA

Kramer White had interviewed for that co-op in January 1986, what would be a pivotal time for NASA. Shortly after, the Challenger shuttle launch shook the world.

"I remember being out in front of the Co-Rec, and on the big screen they were showing the launch. We saw the accident happen, and then a week later, I got my job offer for my co-op position," she says.

With Boilermaker grit, she knew not to shy away from failure. She didn't hesitate to take the job.

On that first co-op tour, Kramer White conducted thermal analysis of the solid rocket boosters and the failed O-ring joint at fault in Challenger. She was thrilled to be on co-op again when the Discovery launch marked the shuttle program's return to flight in September 1988.

She continued working at JSC after graduating from Purdue in 1990. Apollo-era veterans like Stan Weiss, who had worked on the lunar lander, mentored her through those early years. They gave her good projects, let her make mistakes, and watched her grow in her roles. She rose through the ranks to working in the chief engineer's office for space shuttle.

Kramer White is proud to have touched every single orbiter. She loved her trips to Palmdale, California, for their maintenance and modification periods, and the hands-on nature of that work. Her responsibilities spanned from maintenance to flight certification of the wings, tail, flight surfaces and other structures. A lot of the development involved making them lighter weight, improving capabilities and allowing heavier payloads, to support building the International Space Station (ISS).

"I became very attached to the orbiters. They're a little bit like children, with their own unique attributes," she says, pausing, stifling a sigh. "Columbia, being built very early in the program, had a lot of unique attributes."

Processing the loss of Columbia

In February 2003, Kramer White was in California for training when she got an early morning call from her husband. Space shuttle Columbia had broken apart on reentry. She had to get back to Houston.

She immediately called a travel service and negotiated for 9 a.m. flight out of San Jose.

Julie Kramer White has worked at Johnson Space Center since the mid '80s, when she first stepped foot there as a co-op student conducting thermal analysis.

NASA PHOTO

When she arrived, it was already clear that something had happened with the wings. Her job those first few weeks was to drive around to various debris fields near Lufkin, Texas, and identify the pieces. She spent the following five months at Kennedy Space Center in Florida, as part of the failure analysis and materials teams. The workload was her way of dealing with the loss.

"For those of us who spent our careers working on this spacecraft, really your entire reason for being is to help prevent something like this from happening. So it was really hard for us, having lost the crew as well as the vehicle," she says.

"To be out in the field, working long days, long weeks, down in Florida, working toward understanding what happened, and getting us back to flying, and dealing with the corrective actions that fell out of that — for me, that was the best place to process the accident."

Building a family, and a spacecraft

Kramer White took a leave of absence afterward, taking time to reset, focus on herself. She and her husband, Robby, had a child, Cecelia.

Returning to work at NASA's Engineering Safety Center, she soon saw an opening for chief engineer on the Artemis mission's crew capsule. Having worked for more than a decade on a vehicle design she inherited with shuttle, she couldn't miss the opportunity to make something completely new.

"Sustaining a vehicle is totally different than taking it from early concept development through requirements, bringing on a prime contractor, and then dealing with all the trials and tribulations it takes to get from paper to flight," she says. "I pestered the engineering leadership to death, telling them why I would be great at this. They eventually acquiesced, and I stayed there for 11 years."

Cecelia grew up alongside the Artemis crew capsule, which would later be named Orion. She went to every major flight test. She frequently heard Mom on the phone at the kitchen table, debating design decisions well into the evening. Balancing the work, Kramer White also leaned into her crafting hobby, supporting Cecelia's interest in musical theater by building sets and sewing costumes, and creating just about anything out of paper-mache.

But Cecelia didn't want to work at NASA until she learned they had graphic arts internships.

"Last summer, she worked at JSC doing illustration for Artemis public outreach. She came home every night and peppered me with questions on programs, people, history, relationships, NASA vision and mission," Kramer White says. "She loved the people and their passion for their work, and using her skills to represent the mission through her art — and making the mission accessible to normal (non-engineering!) people."

Kramer White has been director of engineering at JSC now for more three years, serving three years as deputy director before that. With shuttle retired and ISS having less than a decade remaining, NASA is letting commercial operators dominate low Earth orbit (LEO). Kramer White's got eyes on the moon and beyond.

"We're busier than ever. I'm looking at integration on the lunar surface, in-situ resource utilization, extending our human presence away from LEO," she says.

It's a big opportunity for anyone looking to NASA for a co-op or internship, like she did: "You'll show up, they'll give you a job, and you'll say, 'I can't believe they're letting me work on this.'"

A lifetime of service

Her dedication has earned Kramer White a long list of NASA medals and awards, plus the 2017 Outstanding Aerospace Engineer and 2023 Distinguished Engineering Alumni awards from Purdue. Like the Apollo-era veterans who ushered her entrance to public service, Kramer White's contributions continue to form pillars underneath the next generation of leaders in aerospace.

But 30 years of Texas sun can't bleach the Midwest modesty out of her. Even in her corner office, inches away from a picture with a United States president, she still can't believe it. She's astounded to see her name alongside others who have received those awards.

Like her NASA mentors, Kramer White would likely deny it — but she, too, is a titan of aerospace.

A diverse employee base is important to NASA's future success, Julie Kramer White says. She makes regular visits to Purdue, inspiring students in the Women in Engineering Program and Minority Engineering Program with the opportunities available to aerospace engineers.

PURDUE UNIVERSITY PHOTO/ALAN CESAR

BLACK AND GOLD WITHIN NASA

According to engineering director Julie Kramer White, 5% of all the engineers at Johnson Space Center are Purdue alumni. Only Texas A&M and UT Austin have more — which Kramer White attributes to their proximity to Houston. Look for these Boilermakers in current and future stories on our website or and our social media.

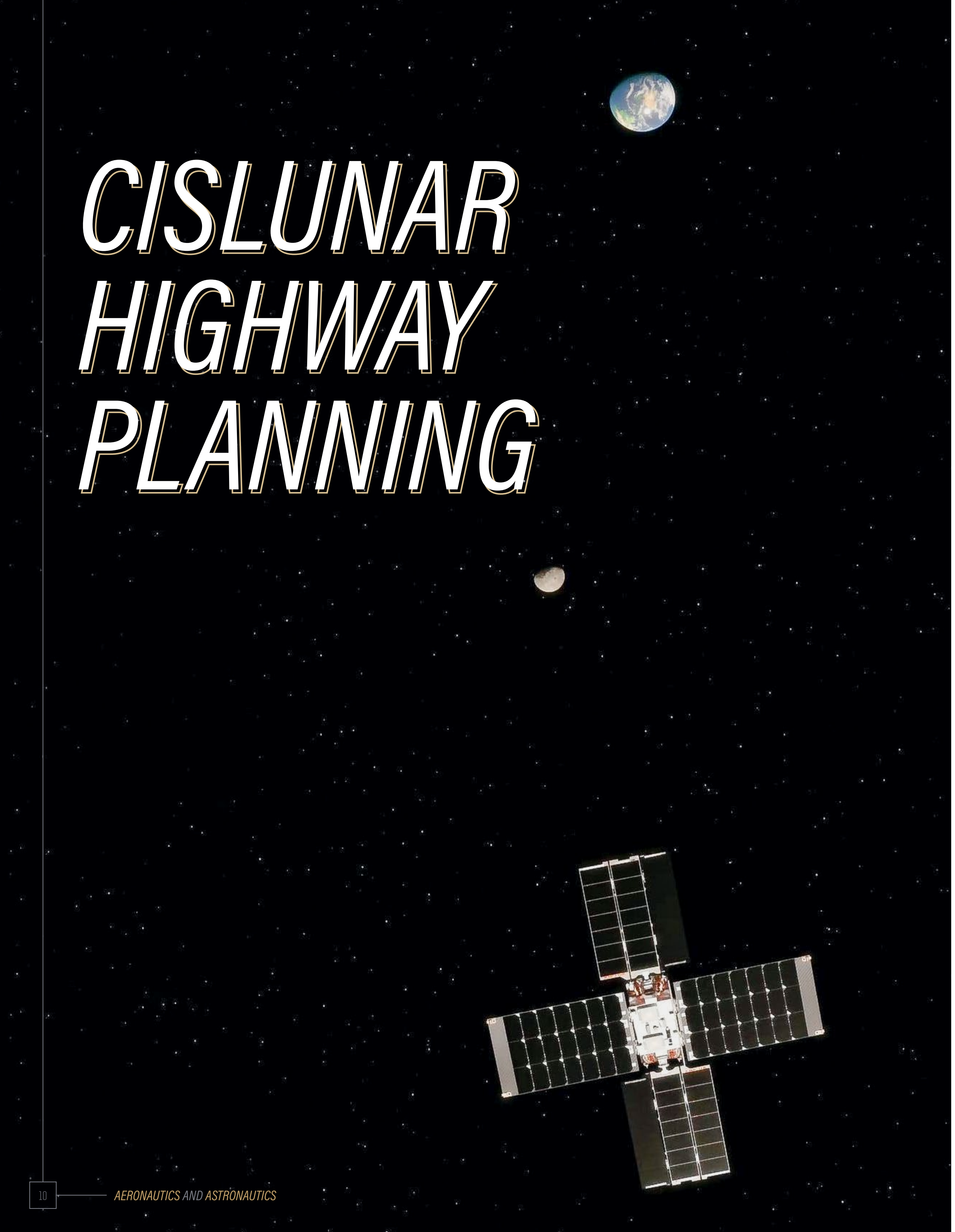
Sean Anderson
(BSAAE '21)
ADCO Flight Controller

Ray Bigonesse
(BSAAE '94)
Rendezvous Officer for Starliner

Allison Bolinger
(BSAAE '04)
Flight Director

Allison Battocletti Noffke
(BSAAE '11)
Spacewalk Operations Manager

Emily Zimovan Spreen
(BSAAE '15, MSAAE '17, PhDAAE '21)
Astrodynamicist for Gateway Mission Design



CISLUNAR HIGHWAY PLANNING

With $4.5 million in USAF funding, a Purdue-led project will build trajectory design tools for future trips to and from the moon

Purdue University is collaborating with three other institutions to build the foundation for space operations to, from and throughout the Earth and moon neighborhood. This area, called the cislunar region, is an enormous, three-dimensional volume of space with many complex factors to be incorporated by mission planners and spacecraft designers.

Teams from the University of Texas at Austin, Penn State and Georgia Tech as well as Purdue will look at challenges to path planning, navigation and control, within the context of space domain awareness in cislunar space. They plan to improve the understanding of pathways throughout the region, and leverage these insights to track and predict the locations of objects beyond geosynchronous orbit (xGEO). The unique dynamical characteristics of this region of space and the associated pathways will then be incorporated into spacecraft navigation and control responses.

The resulting tools will aid government agencies and commercial operators to successfully operate missions in cislunar space — and even into deep space — more sustainably.

This multidisciplinary and intercollegiate proposal, called the Characterizing Highways and Automated Navigation in Cislunar Environment (CHANCE) project, received $4.5 million in funding from the Air Force Office of Scientific Research (AFOSR) in July 2023.

Getting to the moon is hard, rendezvous with Gateway will be harder

Though humans first landed on the moon more than half a century ago, getting there (and staying there) still isn't easy, says Kathleen Howell, the Hsu Lo Distinguished Professor of Aeronautics and Astronautics at Purdue and principal investigator on CHANCE.

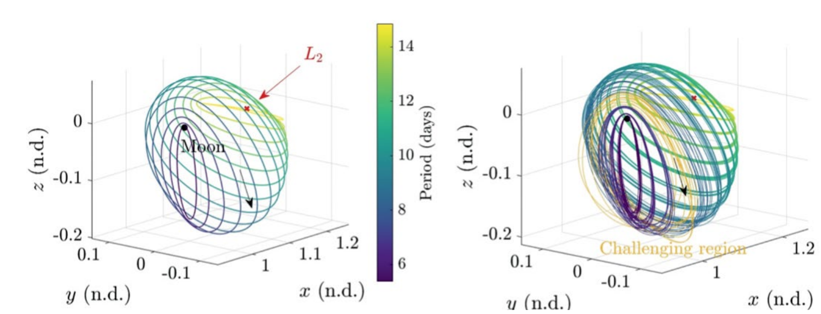
At its core, CHANCE is about describing and communicating the infinite number of complex orbits possible in cislunar space. This work is foundational even for practical trajectory studies: It aims to develop the right data structures and computational algorithms for planning and assessing the orbital trajectories, while also supporting the needs of navigation and control system designers.

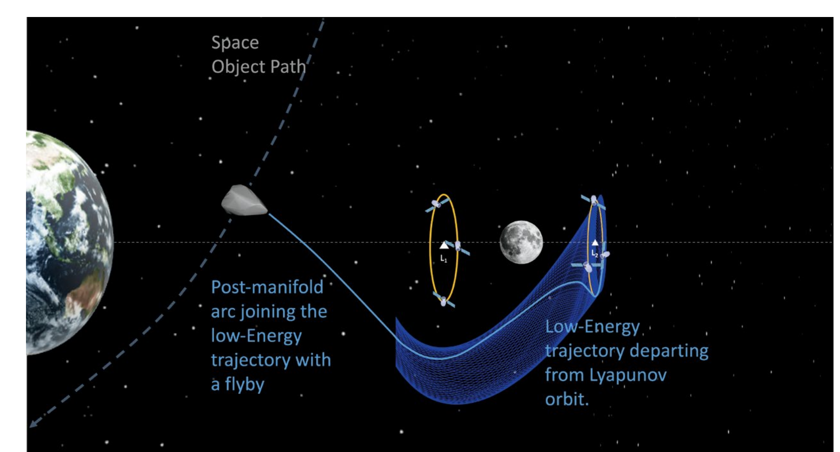
"For Apollo, the mission was to get to the moon, visit briefly, come back. If we want to stay, we have to know how the environment evolves over time and the other opportunities there are for return as well as move throughout the region," Howell says. "Getting to [the Lunar] Gateway is particularly difficult because we'll be going to an orbit that is not as familiar and has not hosted a such a facility previously for long-term operation, which is, in some ways, more challenging than landing on the moon."

Opposite page: Space vehicles like Lunar Flashlight, which will map ice in shadowed regions of the Moon, will benefit from the advanced trajectory mapping and autonomous navigation tools being developed in the Purdue-led project on Characterizing Highways and Automated Navigation in Cislunar Environment (CHANCE). ILLUSTRATION COURTESY NASA JPL

Below: CHANCE will address challenges with Earth-Moon L2 halo orbits and Circular Restricted 3-Body Problems (CR3BP). The diagrams show these orbits in the CR3BP (left), and transitioned to an ephemeris model including a notable region (in yellow) with particularly challenging dynamics for transition.

Bottom: This trajectory design schematic shows rapid response missions to and from quasi-periodic orbits in cislunar space. IMAGE COURTESY OF MARUTHI AKELLA





This foundational work will also support commercial space operators interested in a variety of activities, such as resource extraction, space manufacturing and even tourism. It's a relatively well-known process to operate and launch satellites into low Earth orbit (LEO) — where Earth's gravity is the primary factor — thanks to the tools developed in recent decades.

"An orbital catalog for trajectories generally in Earth orbit is also available. In LEO, there are certain characteristics that govern spacecraft motion, and catalogs are built upon these characteristics. In cislunar space and xGEO, the use of the same characteristics may no longer be a complete approach to represent many of the trajectories in the xGEO regime," Howell says.

Part of the research will be in determining ways to locate an object and to track what's out there, as well as maintain contact. "If I'm trying to track an object, I need to know how to find it and how to best leverage the sensors. With an infinite number of trajectories, it is not even trivial to determine the path and predict object's future trajectory," she says.

Sensors and systems are challenged in the cislunar regime

The competing gravitational pulls in cislunar space render a sensitive environment. Accurate mission planning and navigation, and even corrective maneuvers, require a lot of precision.

"Before we can guide the path of an object, we need to know its location. Orbit determination and navigation are all about, essentially, 'Where is everybody?,'" Howell says. "But when you're out there, there are potentially many competing forces consistent with the intensity of the gravity fields. The sensors can only deliver a certain degree of accuracy — the sensitivity to error might be of an order similar to the effect of gravity."

Self-navigating spacecraft may run into an additional challenge: Limited computing power. As on-board computers are rapidly enhancing their capabilities, autonomy also remains a critical focus of development. Although autonomy is not a focus of this project, it is nevertheless an important development effort for expanded mission options farther from Earth.

"As we plan for potentially more human-crewed missions in cislunar space, it is ever more crucial to gain that critical understanding of the environment as well as a capability for successful navigation and guidance. For successful operations of any vehicle, we don't want to send it off on a path that's got only a 50% chance of getting to its destination. Especially if there are humans on board, it has to be accurate 100% of the time to get them home."

THE CHANCE TEAM

PRINCIPAL INVESTIGATOR

Kathleen Howell
Hsu Lo
Distinguished Professor
Purdue University

CO-PRINCIPAL INVESTIGATORS

Kenshiro Oguri
Assistant Professor
Purdue University

Puneet Singla
Professor
Penn State

Roshan Eapen
Assistant Professor
Penn State

John A. Christian
Associate Professor
Georgia Tech

Maruthi Akella
Professor
University of Texas

COLLABORATORS

David Arnas
Assistant Professor
Purdue University

Anton Leykin
Professor
Georgia Tech

Diverse teams produce better results

It's not enough that Howell is a world-renowned expert in multi-body dynamics, or that other leading universities are involved. She shares the Air Force's perspective that bringing in many voices to a large project like this will produce a better result.

"You can never solve all these problems with only one head. We need more experienced engineers as well as younger researchers. Everyone on the team brings an important perspective that we can't do without. If you don't include those voices, you may miss the key element of any particular problem," Howell says.

The CHANCE team is substantial, with three full professors, one associate and two assistant professors, and two professors as collaborators. Still, they boast their greatest asset is a squad of 14 graduate students. "They will bring energy," Howell says. "We want students from different universities to think and interact. Plus, these students aren't just carrying out a specific set of steps, they're offering significant assistance."

It's big and ambitious, but Howell believes this team can push the work required to make these next giant leaps in human space exploration. It also speaks to her personally.

"I've been working in this field for a long time. This project affords an opportunity to expand into space in a sustainable way. If we want to move through the solar system, we'll need to know how to do all of this."

"And besides," she adds, "I like a challenge."

Distinguished AAE professor **Kathleen Howell** was selected to deliver the keynote address at Purdue's spring 2023 commencement ceremony for master's and doctor of philosophy students.

This continues the university's commencement tradition of the president inviting an esteemed university faculty member to address students during the graduate degrees ceremony.

Watch her speech at bit.ly/howell-graduation

PREPARING FOR COLLISIONS AROUND THE EARTH AND MOON

Carolin Frueh is investigating how to observe and track human-made objects traveling in cislunar space — the area around the Earth and moon — and predict where pieces will go if they crash or explode.

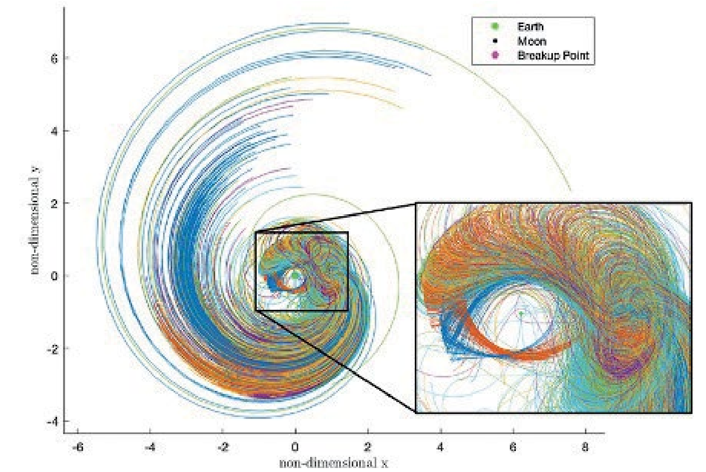
"We are laying the foundations that we believe will shape how space traffic management problems are addressed in the cislunar region," said Frueh, the Harold DeGroff Associate Professor of Aeronautics and Astronautics.

Approximately 130 million pieces of space debris surround Earth — much of it pieces of satellites that exploded or collided with other objects. Frueh works with international space agencies to improve debris tracking databases, but there aren't yet any telescopes in the cislunar region that can support this work.

Frueh and her PhD student, Surabhi Bhadauria, are developing "visibility maps" that would show the best areas to deploy telescopes to track human-made objects, active or dead. These maps better address constantly changing positions of the Earth, moon and sun, which affect what a telescope sees at any given moment. They also run faster and are more comprehensive than existing methods.

But even when telescopes are in place, the satellites they track will likely just look like white dots or streaks. Frueh is accustomed to gleaning meaningful information from these shapes, having done this for near-Earth satellites already. She's working on a method to discern the orbits that a satellite is using to do its mission.

And when a collision inevitably happens? She's thinking ahead, working to estimate the damage an accident could cause. She and another PhD student, Arly Black, showed that pieces from a fragmented satellite can travel effortlessly all the way back to Earth from deep in cislunar space.



Depending on the location, fragments of an exploded spacecraft near the moon could travel millions of miles within just a month's time. IMAGE COURTESY OF ARLY BLACK AND CAROLIN FRUEH

Carolin Frueh is the Harold DeGroff Associate Professor of Aeronautics and Astronautics, effective July 1, 2023. This is one of multiple new term-named professorships established through a generous gift from an AAE alumnus.

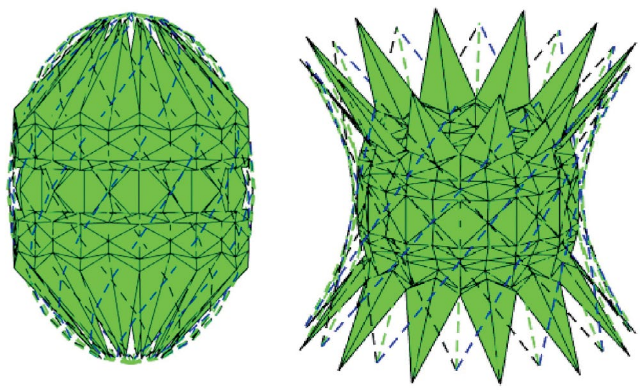
MAKING SPACE TOOLS POSSIBLE THROUGH ORIGAMI

The ancient art of folding paper into complex shapes is inspiring new ways to deploy instruments in space.

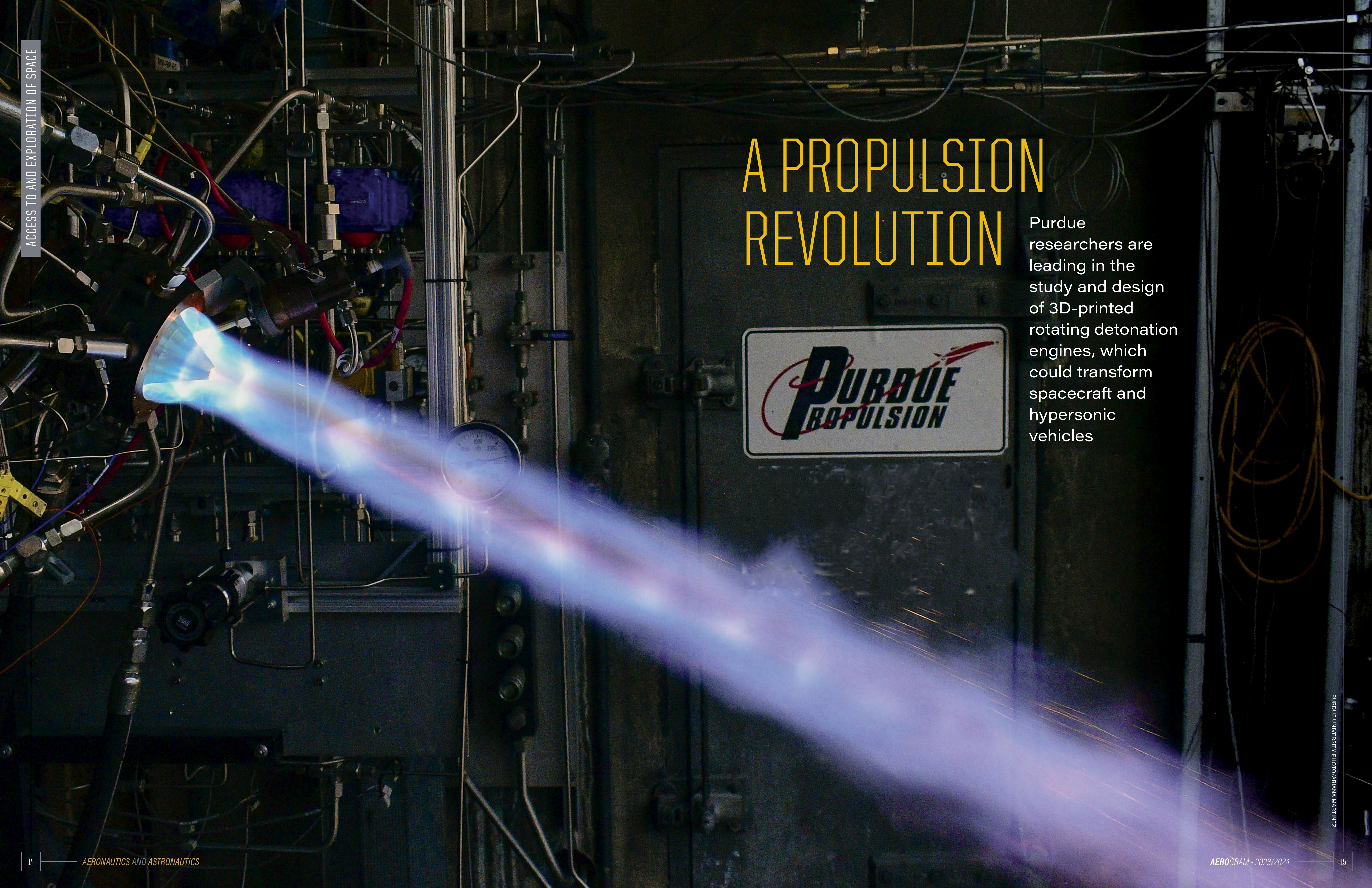
Ran Dai, associate professor of aeronautics and astronautics, is leading a multi-university effort to automate the unfolding and re-folding of spacecraft components like solar panels and sails, temporary habitats and even robotic arms.

"There are unfolding mechanisms for one-time solar panel deployment after launch, but multiple-time automatic folding and unfolding on board have not been realized," Dai says. "For example, we may fold large solar panels under the risk of damage from space debris, and redeploy them after the risk has passed."

Dai is the principal investigator on a collaborative proposal now funded by a $1 million grant from the National Science Foundation. Purdue, Stanford University and the University of Washington will share the grant.



This illustration shows how one designed origami crease pattern would fit both a 3D elliptical surface (left) and a hyperbolic surface (right). PURDUE UNIVERSITY IMAGE/AUTOMATION AND OPTIMIZATION LABORATORY



A PROPULSION REVOLUTION

Purdue researchers are leading in the study and design of 3D-printed rotating detonation engines, which could transform spacecraft and hypersonic vehicles

PURDUE UNIVERSITY PHOTO/ARIANA MARTINEZ

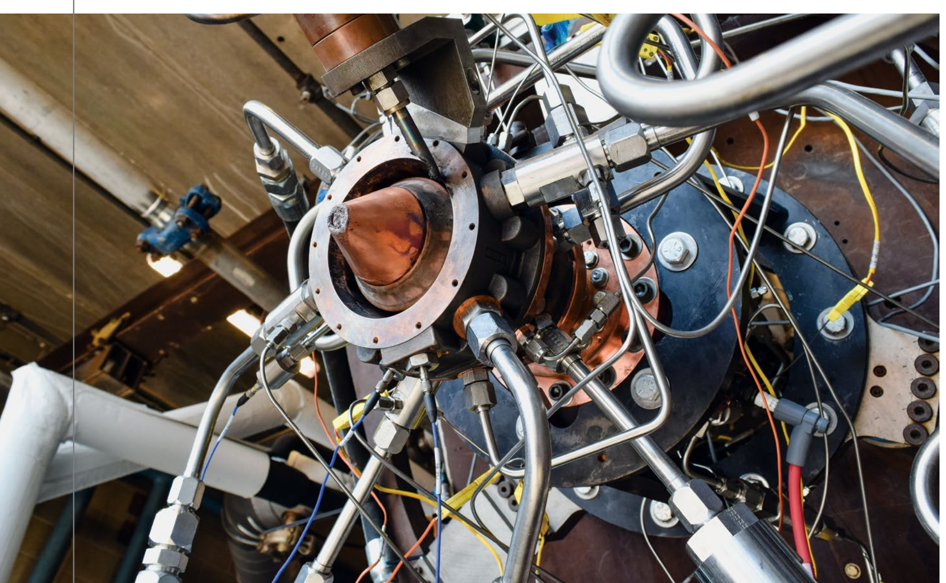
The next generation of propulsion is closer than ever.

A revolutionary design, called a rotating detonation engine (RDE) has been the elusive the "holy grail" for decades. The supersonic dance happening inside an RDE promises to generate the same or more thrust as traditional rocket engine, but in a much smaller package.

After years of slow but steady progress, RDE development is now blazing — and Purdue's early start, unique capabilities and top-level expertise put Boilermakers at the forefront of this field. Purdue researchers even contributed to NASA's first full-scale test of this technology in 2022 (see page 19).

Into the air and space

Stephen Heister, the Raisbeck Engineering Distinguished Professor of Aeronautics and Astronautics, draws a comparison between a rotating detonation rocket engine (RDRE) and NASA's time-honored



In a rotating detonation engine, the combustion wave propagates continuously around the ring-shaped channel between the inner and outer sections. The liquid-cooled engine above, designed at Purdue and 3D-printed by NASA, still fires up even after enduring dozens of runs at Zucrow Labs.

PURDUE UNIVERSITY PHOTO/ ALAN CESAR

RL-10. Originally designed in the 1950s and used on countless satellite and deep space exploration launches, versions of that rocket engine are still part of satellite launch systems today.

An RDRE that produces similar thrust to the RL-10 could be as much as 40 percent shorter in length. That factor alone could be transformational for spacecraft design.

"If we want to do a Neil Armstrong and land on the moon, one factor in the design of the lunar lander is the length of the rocket underneath it. With a shorter engine, you could have shorter landing gear, meaning the lander can fit in a smaller launch vehicle. If we do everything right, an RDRE with just a few percent more thrust could double the payload of the launch vehicle," Heister says.

This game-changing engine design is also useful in Earth-bound applications. Carson Slabaugh, the Paula Feuer Associate Professor of Aeronautics and Astronautics, is looking at RDEs for high-speed vehicles traveling within the atmosphere.

"Aircraft weapons bays are not getting bigger, and yet we want longer range and higher flight speeds from those missiles," Slabaugh says. "These engines give us a step change, a big jump in efficiency to make those things possible."

Remarkable plumage

Rotating detonation engines try to harness what's called combustion instability — a phenomenon that engineers try to eliminate in traditional rockets. These uncontrolled acoustic instabilities can, under the right circumstances, grow in strength to supersonic detonation waves inside a combustion chamber. Many failures on traditional rockets have been attributed to this instability because the chamber was not designed to sustain them.

Researchers have been trying to exploit the waves by inducing them inside a ring-shaped channel. If they get the shape and injection conditions right, these shockwaves don't bounce back and forth: They whiz around the ring at supersonic speed, compressing and burning the air-fuel mixture as they go. That is, if you can keep them going.

"In an RDE, the burning process is unsteady, making it really hard to sustain. These waves move at more than a mile per second, which means we've got about 100 microseconds between each wave passage to inject propellants and get them mixed," Slabaugh says. "It's a challenge to diagnose what's happening and make design decisions."

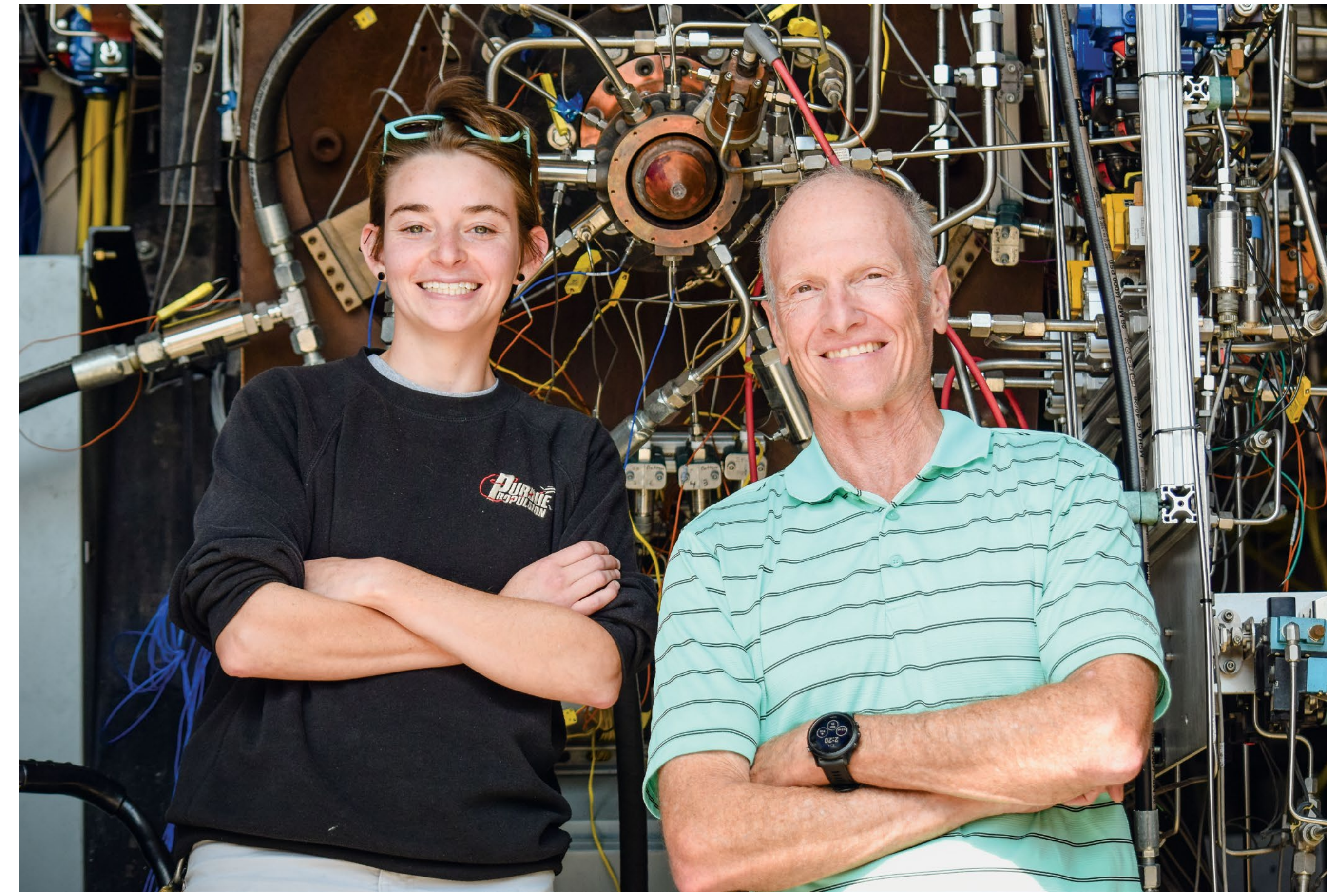
These challenges are what make Purdue the best place for RDE research. Heister has been working on these designs since 2007, and Slabaugh has developed diagnostic techniques for high-speed combustion. Zucrow Labs has the high-speed lasers, cameras and other tools needed to make sense of the complex thermal fluxes happening inside the combustion ring — not to mention the fuel supply to fire one up.

"RDEs consume a tremendous amount of propellant, and if you try to make it too small, it just won't work. You need flow systems that are only available at Zucrow to successfully test these," Slabaugh says.

The result, once you have it going, is a high-temperature dance that produces a lot of heat, a lot of thrust and a gorgeous blue-purple spiral of perfectly spent kerosene.

Water-cooling for longer life

The level of development and testing happening now at Zucrow Labs is unrivaled in academia, Heister says. Other universities running RDRE combustion experiments are burning gaseous fuel and oxygen, and with engines that use a solid metal center to absorb its copious heat energy. Those can only run for about a second before the metal reaches thermal capacity and begins melting away.



AAE doctoral student Ariana Martinez with Stephen Heister, the Raisbeck Engineering Distinguished Professor of Aeronautics and Astronautics.

PURDUE UNIVERSITY PHOTO/ ALAN CESAR

While useful for research, it's far from the demands of a real-world engine that must run for minutes at a time. In 2022, while studying under Heister, then-student John Smallwood (PhD AAE '23) built and tested Purdue's first water-cooled RDRE. His design endured 120 hot-fires, some with 30-second runs, and still looked pristine when they cut it open afterward.

Encouraged by those results, AAE doctoral student Ariana Martinez pushed further.

"We wanted to bring an aggressive hardware design that takes us one step closer to a flight-like system. This combustor offers elevated chamber pressures, extended run durations, a contoured nozzle and advanced 3D printing techniques," she says.

In her approach, Martinez threw away the limitations of traditional metalworking techniques like computer numerical control (CNC) machining. She looked to NASA's success with 3D-printing an exotic copper alloy, called GRCop-42, and began the engine she called Panther. With her face nearly pressed to her computer screen, Martinez spent countless hours in CAD software to work out the complex geometries needed to make Panther run.

"We wanted to bring an aggressive hardware design that takes us one step closer to a flight-like system. This combustor offers elevated chamber pressures, extended run durations, a contoured nozzle, and advanced 3D printing techniques."

—Ariana Martinez, AAE doctoral student

"Another issue for RDE research is that we're using a liquid fuel. It's much tricker to get a liquid and a gas to mix together properly. Ariana has come up with some clever injector concepts to address that," Heister says.

Martinez collaborated with NASA Marshall Space Flight Center to print the Panther combustor. Over the spring and summer of 2023, she put it through 31 hot-fires for a total duration of 200 seconds.

Data collected on these runs document the heat flux across the RDRE combustor, among other factors. Panther showcased its durability with runs as long as 15 seconds. “The water-cooled hardware would survive if we could continue feeding propellant to it,” Martinez says. “We could run it indefinitely.”

Regulating the battle for biggest detonation wave

Just down the hall at Zucrow Labs building ZL3, Slabaugh is working on engines that don’t bring their oxidizer along for the ride. A missile traveling through the atmosphere can run an air-breathing engine — meaning it burns fuel with oxygen taken from its surroundings.

“An air-breathing RDE has a different set of challenges because we’re stuck with the amount of pressure we can recover from the inlet. The air

Carson Slabaugh is the Paula Feuer Associate Professor of Aeronautics and Astronautics, effective July 1, 2023. This is one of multiple new term-named professorships established this year through a generous gift from an AAE alumnus.

you push into the system is coupled to the vehicle’s ballistics,” Slabaugh says.

One of his graduate students, Ethan Plaehn, has tackled the challenge of how many detonation waves propagate in an engine. That detail had been largely unpredictable before, even between multiple tests of the same engine at the same throttle setpoint.

“Ethan developed an RDE where we can actively change the engine flow path geometry while it’s running. Before this development, we would witness a ‘cage match’ of sorts, where only the strongest waves would survive after ignition. Now, we can control this chaotic process and guide the system into one, two, three or more waves,” Slabaugh says.

“Our goal is to achieve the maximum level of power density and thrust that we can, so this is a big deal. The number of waves can make a big difference. We’re very excited about this new understanding and having an effective control approach.”

NASA TESTS FULL-SCALE RDRE WITH BOILERMAKER SUPPORT

In June 2022, NASA announced completion of a successful full-scale RDRE (rotating detonation rocket engine) test at Marshall Space Flight Center. The liquid-cooled, 3D-printed engine was fired more than a dozen times, totaling nearly 10 minutes in duration, and produced more than 4,000 pounds of thrust at full throttle. The average chamber pressure of 622 pounds per square inch is the highest rating for this design on record.

NASA named IN Space as its primary collaborator. The company is led by alumnus B.J. Austin (BSAAE ’99, MSAAE ’02), Purdue faculty members Steve Heister and Carson Slabaugh, and Zucrow Labs managing director Scott Meyer. This partnership is symbolic of the head start that Purdue researchers have on this type of propulsion.

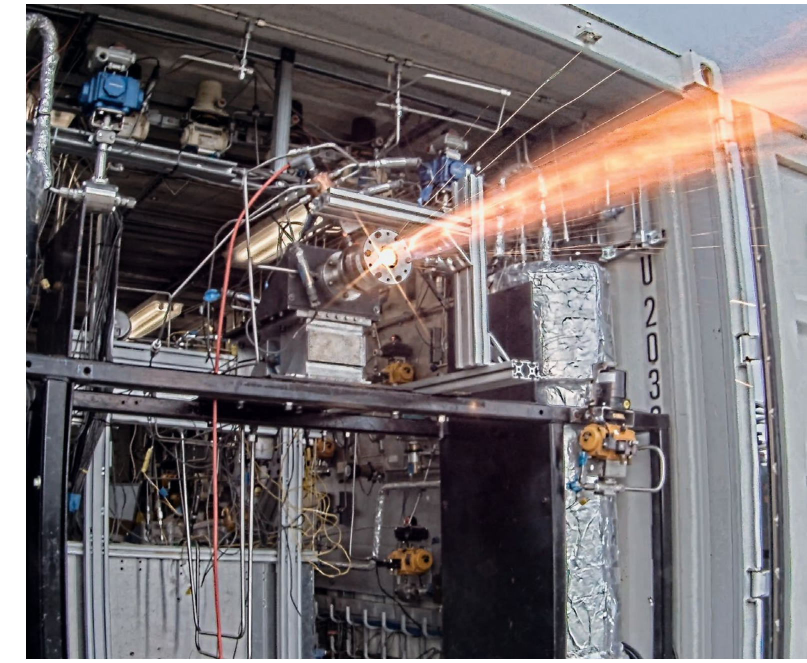
“When we started this company, rotating detonation engines were in their infancy. There was no vision yet for a path to a flight system,” Heister says. “That changed in the last few years.”

But, Slabaugh adds, academic research can only go so far.

“Purdue has an educational mission; our goal is student development. This technology has enough fundamental challenges to keep us busy for many years to come, but academic research will not get us all the way into a flight system,” he says.

Through programs like Purdue Foundry and Office of Commercialization, Purdue encourages and provides funding for faculty to start new companies with their breakthroughs. Partnering with outside organizations help bridge the gap from the laboratory to the engine.

Listen to Heister talk about this technology on NASA’s “Houston, We Have a Podcast,” episode 296.



$ PER POUND:

PROPULSION STUDENTS BUILD COST-CONSCIOUS ROCKET ENGINES

In spring 2023, a course split into two teams to see who could design, build and test the best rocket engine for less than $1,500. Carson Slabaugh, the Paula Feuer Associate Professor of Aeronautics and Astronautics, called for a methane-oxygen engine capable of a steady 300 lbf of thrust for two seconds, and two hot fires.

“Cost overruns kill many programs and always lead to delays. Cost has significant effects on design decisions and, in many cases such as this, force engineers to get creative,” Slabaugh says.

The teams, made up of graduate and undergraduate students, set up and ran the tests themselves at Zucrow Labs.

Team SpaceY designed a single-element shear-coaxial injector and an innovative graphite nozzle to handle the heat, fabricating two copies for $1,196.43. Thrust was just shy of target, producing an average 294 lbf on the best test.

Team Frugal Fire designed a multi-element, impinging injector and used fuel film cooling on the nozzle. To reduce cost, the team machined the injector plate themselves and used brass and carbon steel materials. Total cost: just $652.38. Their output, 307 lbf, was impressive, but fuel film cooling wasn’t enough: The nozzle melted down during its first run, leaving no time for a second test.

Team SpaceY was declared the winner on spec, but Frugal Fire’s experience was also an opportunity for rocket forensics. It led to in-depth discussions with Slabaugh on combustion instabilities — a lesson they wouldn’t have gotten with a successful test.

“It was a formative experience,” said Christina Huynh, an undergraduate student on the SpaceY team. “This class is why I came to Purdue.”

Both teams made video recaps, posted to YouTube under the Purdue Propulsion channel: bit.ly/purduepropulsion

[TARGET IDENTIFIED]

PROGRAMMING CYBORG EYES FOR THE U.S. NAVY

Kraken, a student-built drone identical to the one in the illustration above, will model an aggressor aircraft in a Purdue-Saab project to design a threat identification system for the U.S. Navy.

DRONE PHOTO COURTESY PURDUE AERIAL ROBOTICS TEAM
ILLUSTRATION BY ALAN CESAR

It's not unusual to see through the eyes of a robot or cyborg, at least in science fiction movies. The screen might show a pixelated world with a high-tech overlay, identifying people by body type, and motorcycles by make and model. If a person's clothes and ride are suitable, the Terminator can even tell if the owner is likely to put up a fight.

That type of artificial intelligence may not be far in the future, albeit in a more defensive position and with less emphasis on Harley Davidsons. With $13 million in funding from the Office of Naval Research, Saab has partnered with Purdue's Institute for Control, Optimization and Networks (ICON) to develop AI models that can automatically spot threats in a complex, dynamic naval battlespace.

Those models will provide human-readable information to people who can decide whether to engage with a potential threat.

The TSUNOMI program (Threat and Situational Understanding with Networked-Online Machine Intelligence) hopes to deal with an increase in intrusions into sensitive areas and serious physical attacks on critical infrastructure, both in military and civilian domains.

"There is an urgent need to create technological solutions that allow networks of sensors equipped with sophisticated AI to quickly detect and identify potential threats," says Arvind Raman, the John A. Edwardson Dean of the College of Engineering.

Though these technologies are first intended for naval use, they will be adaptable: A Saab release says this system could be paired with radar systems at military and commercial airports, complementing the company's growing portfolio in the U.S.

From many sensors, one sense

Shaoshuai Mou, co-director of ICON and co-lead of the TSUNOMI project, says one of their challenges will be determining how to combine information from many sensors to identify what is in that space.

"We will be doing data fusion with information from different sensors, to determine what is there," Mou says. "If we want to determine if something is a table, we might look for four corners, measure its height and compare it to what we know. It's the same with a target: An object's shape, flight speed, the noise it makes and other variables can help to determine if it's a threat or not."

Developing these data fusion models can also provide guidelines on how many sensors, and of what type, might be needed to effectively survey a particular area. But identifying a drone is only part of the problem: Pinning down intent requires a nuanced look at how it behaves.

"Every autonomous vehicle has a mission, what we call an object function." Mou says, "We can use inverse optimal control and optimal control methods to figure out the object function of its autonomous system. With that, we can predict its future trajectory. If it's headed to a sensitive area or not, for example, can tell us a lot about what it intends to do."

AI plays a key role

In this context, the machine-learning (ML) AI algorithms have to satisfy three key criteria, says Christopher Brinton, the Elmore Assistant Professor of Electrical and Computer Engineering and co-principal investigator on TSUNOMI.

First, the AI must make accurate decisions in identifying and categorizing threats. The other two, Brinton says, are less obvious: It must be light on resources, and be able to share the context for its decisions.

"Resource utilization is a crucial objective, as many naval systems are pushing for reductions

Shaoshuai Mou is the Elmer Bruhn Associate Professor of Aeronautics and Astronautics, effective July 1, 2023. This is one of multiple new term-named professorships established this year through a generous gift from an AAE alumnus.

PHOTO COURTESY PURDUE AERIAL ROBOTICS TEAM

THE KRAKEN RISES

The Guapo UAV, pictured above with the Purdue Aerial Robotics Team (PART), was built for the international sUAS Competition in 2023. PART placed 13th overall and 3rd among U.S. schools. The Kraken, which is being used for data collection on the TSUNOMI project, was built using the same composite molds and looks identical to Guapo.

However, everything from the composite materials to the internal structure is different, allowing Kraken a lower takeoff weight and a better flight envelope. PART system leads Aidan Bilger and Mateo Llerena headed the Kraken build. "We will be acting in an aggressor role initially, replicating adversary UAS threats," Bilger says. "This aircraft is excellent as an aggressor because of its flexibility. Our ability to operate autonomously allows us to replicate our flights, which is critical to another important factor: consistency."

The PART team included more than 30 students across engineering disciplines. The subsystem leads on the team were: Matthieu Opdyke, Eric O'Keefe, Corey Auerbach, Aidan Bilger, Mateo Llerena, Diego Montes, Evan Kamm, Cameron Johnson, Kevin Cai and Leonard Jung. Charles D'Onofrio was the team's graduate student mentor.

KRAKEN UAV SPECS

40 LBS THRUST	30 KNOTS CRUISE SPEED
10K FEET SERVICE CEILING	50 MILES MAX. RANGE
60 MIN MAX. RUN TIME	14 FEET WINGSPAN
60 LBS MAX. TAKEOFF WEIGHT	<100 FT TAKEOFF DISTANCE
20 LBS PAYLOAD CAPACITY	

> "ICON's rapid growth, expertise and significant level of activity make it a top-tier center for autonomous systems research and education."
>
> —Shreyas Sundaram, co-director of ICON and co-lead of the TSUNOMI project

in size, weight and power of their hardware, to provide agility in contested environments. Unfortunately, accuracy is often inversely related to resource utilization, as it takes more computing and communication power to drive inference quality higher," Brinton says.

"Contextual awareness is also critical, as ultimately, a human operator will have to evaluate the decisions that were made through AI/ML, and potentially provide refinements over a longer timescale."

A 'natural fit' for Boilermakers

With the project's expansive scope, it was a natural fit that Saab would select ICON as its partner, says Shreyas Sundaram, co-director of ICON and co-lead of the TSUNOMI project.

ICON has in-house expertise in many of the areas TSUNOMI touches: Its 84 faculty members span the College of Engineering, College of Science, College of Agriculture and Purdue Polytechnic Institute.

"ICON's rapid growth, expertise and significant level of activity make it a top-tier center for autonomous systems research and education. The breadth and depth of expertise within ICON also allows us to quickly pull together key experts to form effective teams to tackle new projects," said Sundaram, who is also the Marie Gordon Associate Professor in the Elmore Family School of Electrical and Computer Engineering.

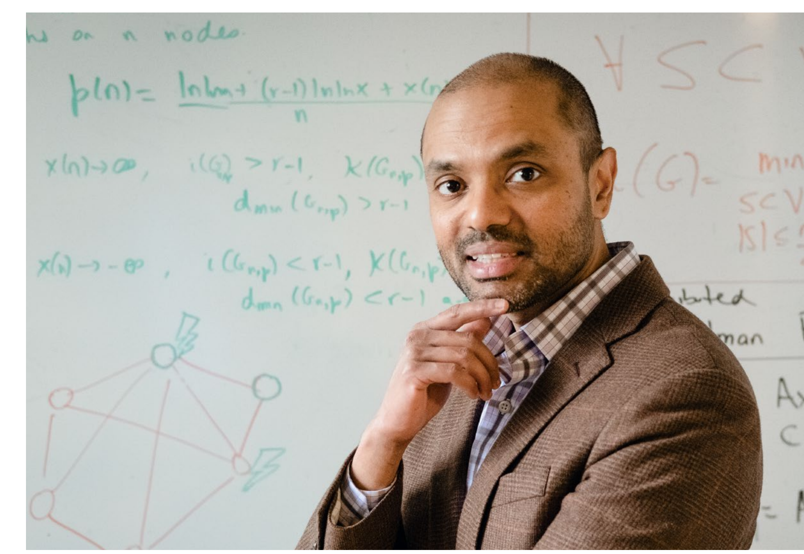
Researchers will use the motion-capture equipment and other tools at the Purdue UAS Research and Test (PURT) Facility as its main research space. Close proximity to Saab's growing presence in West Lafayette, including its advanced manufacturing facility and engineering resources, is another perk of the partnership.

Purdue is expected to receive $4.3 million of the total grant as a subcontractor through Saab. That funding will primarily be used to support graduate students, some faculty time and to purchase sensors.

Erik Smith, president and CEO of Saab, said it's a big win for everyone involved. "This program represents a real step toward robust and trusted artificial intelligence. TSUNOMI will help stakeholders make decisions quicker and with more confidence."

Christopher Brinton, the Elmore Assistant Professor of Electrical and Computer Engineering, is co-principal investigator on TSUNOMI.

PURDUE UNIVERSITY PHOTO/COLLEGE OF ENGINEERING



Shreyas Sundaram, the Marie Gordon Professor in the Elmore Family School of Electrical and Computer Engineering, is co-director of ICON and co-lead of the TSUNOMI project.

PURDUE UNIVERSITY PHOTO/COLLEGE OF ENGINEERING

FROST SHOCK

DOD-FUNDED STUDY WILL REVEAL IF ATMOSPHERIC ICE COULD DAMAGE A HYPERSONIC MISSILE

Joe Jewell is melting ice very, very quickly. By dropping ice crystals into a shock tunnel, the associate professor is determining the risk that atmospheric particles pose to vehicles that travel at Mach 5 or higher — the hypersonic threshold.

"Dust particles, rain, snow, these are usually pretty benign if you're traveling slowly. But even at airliner speeds they can cause problems," says Jewell, the John Bogdanoff Associate Professor of Aeronautics and Astronautics. "So if you're traveling at Mach 6, the uncertainty only gets larger for little particles like ice crystals. Kinetic energy goes up with the square of the speed, so a particle at Mach 6 has 36 times more energy than at Mach 1."

The U.S. Navy's Office of Naval Research, which has defense-related interests in hypersonic vehicles, has awarded $750,000 to the University of North Dakota and Purdue to study what happens when ice crystals slam into a hypersonic shock wave. Jewell is partnering with UND researchers Hallie Chelmo, in mechanical engineering, and David Delene, in atmospheric sciences, for their expertise in making and characterizing atmospheric ice crystals.

Chelmo, who is the principal investigator on this project, says computational researchers across the country are looking for this kind of experimental data in order to analyze the physics inside the shock wave ahead of a hypersonic vehicle.

"That is exactly what we're developing," Chelmo said. "We're developing new methods to fundamentally understand shock wave-particle interactions, and we'll give that data to the computational researchers."

Can a hypersonic shock wave melt ice?

This study of atmospheric ice crystals is an effort to pin down design criteria for hypersonic vehicles and their propulsion systems. As seen after the 2010 eruption of Eyjafjallajökull, a volcano in Iceland, microscopic particulates like ash can build up in the heat of an aircraft turbine engine and cause it to seize up. Volcanic ash can also scratch airplane windows so badly that it becomes difficult for pilots to see.

But while the threat from particulates is obvious, water and ice are curiosities because they change phase more readily. The question is whether hypersonic vehicles — like missiles flying toward their targets, or spacecraft reentering the atmosphere — are vulnerable.

"Air can be quite cold in the atmosphere, and yet a vehicle passing through it at Mach 6 or some other number can be quite hot. A hypersonic vehicle develops a shock wave in front of it, and the gas behind the shock wave is higher pressure and temperature. Certainly the gas is hot enough that if ice were to sit in it, it would melt," Jewell says.

"The question is, will ice actually melt in the very short time before it hits the vehicle? It may melt partially, or may melt completely. Or it might stay mostly intact. That hasn't been studied very much. We aim to fix that."

How to capture a shock wave on camera

This interdisciplinary research project is something neither institution could do on their own, Jewell says. "That's why it's a good collaboration. I know very little about ice crystals, but I know a lot about shockwaves."

Atmospheric ice like this is tricky to make, Chelmo says. You don't just fill a tiny tray and stick it in the freezer — ice will build out from the walls, or from whatever solid it's clinging to. The expertise at UND is in their method of creating realistic ice aggregates in a repeatable way: "We need to actually keep them levitated to not physically

Joe Jewell is the John Bogdanoff Associate Professor of Aeronautics and Astronautics, effective July 1, 2023. This is one of multiple new term-named professorships established this year through a generous gift from an AAE alumnus.

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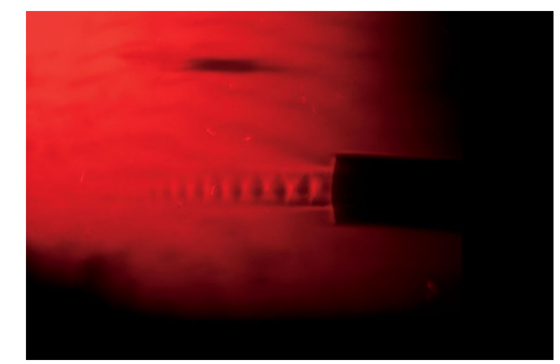
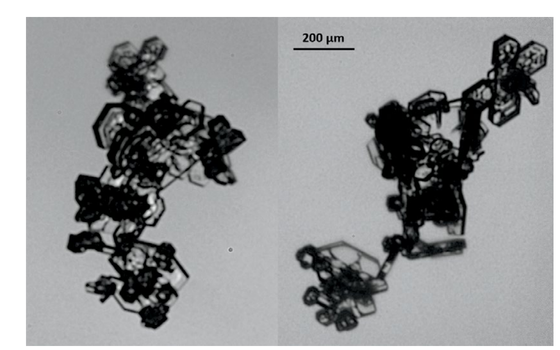
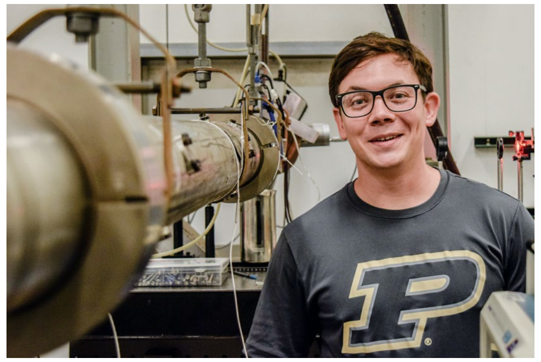


This demonstration of Schlieren videography shows diamond-shaped pressure gradients in the air exiting the nozzle of an aerosol duster spray can.

PHOTO BY JOE LAVALLEY

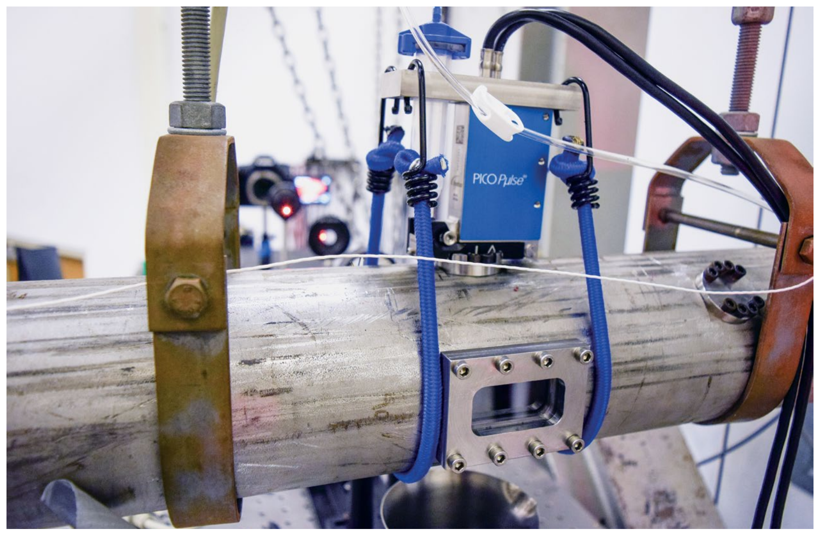


Representative in situ stereo images of small ice crystal aggregates, roughly 200 micrometers wide, present in most cirrus clouds. Hallie Chelmo and David Delene at the University of North Dakota will be providing ice crystals like these for testing in shockwaves at Purdue. IMAGE PROVIDED BY DAVID DELENE/UND



AAE student Joe Lavalley (BSAAE '22) from Valparaiso, Indiana, is assisting in the research project.

PURDUE UNIVERSITY PHOTO/ ALAN CESAR



A test section of this shock tunnel has been fitted with a device that releases tiny water droplets in line with the viewing window. The water droplets will provide experimental results while also helping determine the appropriate timing for the shock wave when it comes time to test ice crystals.

PURDUE UNIVERSITY PHOTO/ALAN CESAR

interfere with the freezing process, to mimic ice formation in the atmosphere," she explains.

The crystals are also tiny, on the order of 200 micrometers. Up close, they are "complex like snowflakes, but they don't have the same fractal patterns. This indicates different formation pathways that are poorly understood at the moment. They are also smaller than snow and hail that fall to the ground," Chelmo says.

Jewell's shock tunnel, on the other hand, is a relatively simple device — albeit very precise in its details — that will pummel these tiny crystals as they fall. At its most basic, a shock tunnel is a closed, straight tube that can be split into sections, with a diaphragm in between. After drawing a vacuum on one side, breaking the diaphragm will send a shock wave propagating down the other side.

"It's a lot like what our Mach 6 wind tunnel would do if it didn't have a nozzle," Jewell says. "It's a finely tuned shock tunnel, with ports for pressure transducers on the sides and top. Calibration is its original purpose. Simplicity is its virtue."

AAE students Joe Lavalley (BSAAE '22), Siddharth Bhatnagar and Henry Lewis II (BSAAE '22, MSAAE '23) — who has since graduated and accepted a job at Lockheed Martin — assisted with the research. The team adapted the tunnel to accept the ice and droplet dispenser developed by UND. They also modified the business end of UND's droplet and ice crystal dispensers to fit in one of the spots with slightly bigger ports. A viewing window allows them to directly observe the results — but not with the naked eye.

The team will employ a technique called Schlieren videography, which uses specific lighting conditions to visualize density gradients in a gas. The resulting images will show solids as opaque, with liquids and gases in distinguishable ranges of gray. With a high-resolution monochrome camera capturing up to 1.75 million frames per second, even the pressure wave itself will be visible.

"Shockwaves are very fast, so we need to take lots of pictures to see what happens," Jewell says. "You also can't necessarily trigger the shock wave instantly, there's some delay. We're inserting water droplets frequently enough so there's always one in the window. We'll need to release five to 10 per second so when the shock wave does arrive, there'll be one in the window."

With this work, Jewell is showing that this device can do so much more than calibrate pressure transducers. Going from water droplets to ice crystals, he hopes to improve timing precision of the shock wave, and add more cameras to capture a three-dimensional view.

"This is a useful and underexplored field," Jewell says. "Science is always about the in between cases. That's where the interesting things happen."

SAFE, EFFICIENT AND SUSTAINABLE AIR TRANSPORTATION

FUTURE FUEL

Can biofuels could reduce aviation's carbon footprint?

The aviation industry accounts for about 2.5% of global carbon emissions, and all hands are on deck to lower the number. European aviation set a goal and road map to reach net-zero CO2 emissions by 2050. The International Civil Aviation Organization created incentives for airlines to use sustainable aviation fuel (SAF) to keep sector emissions at their 2020 level.

SAF is a blend of biofuels and traditional jet fuels. It has a lower net carbon footprint because it is grown from crops that absorb carbon dioxide. But it costs more to produce than jet fuel, and the ultimate production capacity is uncertain, says William Crossley, the Uhrig & Vournas Head of Aeronautics and Astronautics.

Looking to the future of this technology, Crossley thought it was important to evaluate how effective SAF could be at lessening carbon emissions. The results were encouraging, but not a silver bullet.

His team developed a simulation, called the Fleet-Level Environmental Evaluation Tool (FLEET), that uses an operations-based model to predict emissions of future airline operations. It looks at varying demand scenarios, improvement of aircraft technology, levels of biofuel utilization and effects of biofuel pricing on what passengers pay for tickets.

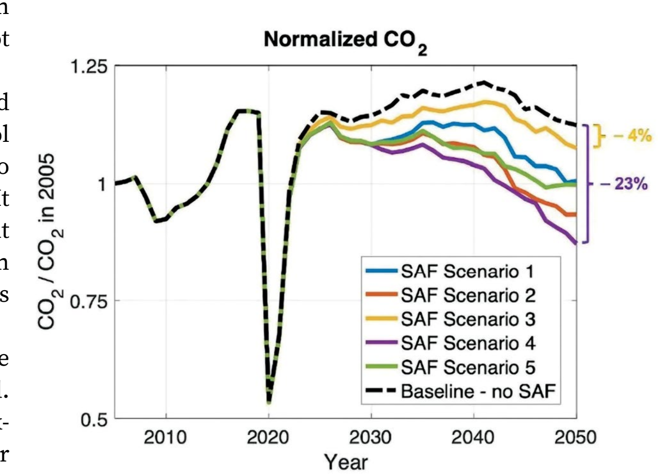
"This modeling system allowed us to simulate different scenarios of SAF use and travel demand. FLEET's optimization algorithm balances maximizing airline profit with fulfilling passenger demand and addressing operational constraints. The model even considers several new technologies that airlines are expected to adopt to help cut fuel consumption," Crossley says.

The team ran the FLEET simulation for 2005-2050, accounting for differing post-pandemic demand recovery scenarios. All the SAF scenarios showed a reduction in CO_2, ranging from 4% to 23% lower than baseline emissions.

"Even if airlines experience and meet higher passenger demand for travel, their carbon emissions still could be lower through the use of SAF than if they use conventional jet fuel," Crossley says. "The up-to-23% decrease is not enough on its own to achieve aggressive CO_2 reduction goals. However, it shows that SAF is one more tool in aviation's toolbox — and a very valuable one — in addressing and mitigating global temperature growth.

William Crossley, the Uhrig & Vournas Head of Aeronautics and Astronautics, led a team evaluating how effective sustainable aviation fuel (SAF) could be at lessening carbon emissions.

PURDUE UNIVERSITY PHOTO/ STACY CLARDIE



This chart shows the projected CO_2 output from the aviation industry over various scenarios. Purdue's model shows that sustainable aviation fuels could reduce net carbon emissions by between 4% and 23% by 2050.

REVOLUTIONIZING RURAL HEALTH CARE

VIP TEAM DESIGNS NARCAN DELIVERY DRONE TO BRING LIFESAVING AID TO REMOTE COMMUNITIES

On a crisp afternoon in October 2022, a student walking on campus encountered an opioid overdose victim laying in the grass. A panicked bystander stood nearby, pleading for help. That help came in the form of a drone carrying Narcan nasal spray. The drone's video screen and audio output instructed the student how to remove the canister and administer the medicine in time to save a life.

The simulated emergency scenario, conducted with a patient mannequin, was part of a pilot study led by Nicole Adams (BS Science '97), clinical associate professor of nursing, and Nan Kong, professor of biomedical engineering, to evaluate the efficacy and efficiency of an individual interacting with an autonomous Narcan delivery drone during a medical emergency.

"My research focuses on health care in rural communities," Adams says. "In rural areas, the median response time for an ambulance to arrive is 13 minutes and 10% of patients wait almost half an hour. When a person stops breathing, we only have six minutes until they die and cannot be resuscitated."

Prior to conducting the study held in fall 2022 at the Alexander Field baseball stadium, the team held a practice run in March 2021 to test an initial prototype drone. Based on the March test run, the team made additional modifications to the UAV.

Adams stressed that drones would supplement ambulances, not replace them. And if proven effective, drones could become a routine tool to provide critical aid in a timely manner during medical emergencies. Although other institutions have run simulated studies involving drone delivery of Narcan, none involved human participants administering the medicine. Kong, who's collaborated with Adams on several projects in recent years, suggested they leverage the Vertically Integrated Projects (VIP) Program in the College of Engineering and partner to design an unmanned aerial vehicle (UAV) prototype that could be used for a drone-delivered Narcan feasibility study with human participants.

"In biomedical engineering, we address problems with the ambitious but clear goal to improve human health," Kong says. "I seek to bridge the gap between a domain expert, such as Dr. Adams, and our engineering students. The goals of this project have important social and economic relevance and I knew it would be a rewarding experiential learning opportunity for the students to apply their technological expertise to solve a problem with real-world impact."

The VIP Program

In VIP, undergraduate interdisciplinary engineers work together in teams on authentic and extended research and design projects related to active research areas of Purdue faculty members and national, international and industry-sponsored design challenges. The Rural UAV Narcan (RUN) team also included nursing students.

"VIP provides a unique opportunity for students to collaborate with faculty and graduate student mentors to address real-world research and design challenges," says James Goppert (BSAAE '07, MSAAE '11; PhD AAE '18), managing director of the Purdue UAS Research and Test Facility (PURT). "VIP students get a jump-start on working in industry and applying skills they are learning concurrently in the classroom. A lot of students discover a passion for robotics or programming they didn't realize they had. VIP helps students determine their path forward."

The multi-semester RUN project began in Fall 2021. In the beginning, the team tackled a lot of product development and user experience design challenges, such as how to mount the Narcan to the drone and release it for use. Throughout the design process, the students would meet periodically with Kong and Adams to discuss their progress.

Members of the Rural UAV Narcan (RUN) team assess their prototype during an outdoor test run held in March 2021.

"The initial drone was designed to drop the Narcan nearby," Adams says. "That might work for a package delivery, but in this case, we need to instruct bystanders on how to administer the medicine. So the students redesigned the drone to include a video screen and audio player to give instructions on how to retrieve the Narcan from the drone and how to administer it to the victim."

The student-designed prototype was built using custom parts created with 3D modeling software and printed and manufactured with campus resources. Much of the prototype testing occurred in the PURT, which opened in Hangar 4 at the Purdue Airport in 2021. At 20,000 square-feet, PURT is the largest indoor motion capture facility in the world.

"The state of the art sensors equipped in PURT provide real-time data that can inform intelligent decisions during the development and testing phase," Goppert says. "We have the capability of synthetically generating GPS signals to envision how a something like the Narcan drone delivery project would play out if you deployed it in an urban canyon, like downtown Chicago, or a more open, rural environment."

The dedicated UAV facility provided students with the space they needed to run multiple tests and fine tune the vehicle design.

The RUN team builds an initial UAV prototype designed to deliver Narcan during an overdose emergency.

The RUN team stands with the Narcan delivery drone and patient mannequin used during the October 2022 pilot study conducted by Nicole Adams (BS'97), clinical associate professor of nursing (at right), and Nan Kong, professor of biomedical engineering.

"PURT is an incredible campus resource that gave us the freedom to rapidly test, fail and test again," says Drew Lundin, an AAE senior from St. Paul, Minnesota, who served as one of the RUN team's student leaders for two semesters. "We can repeat our mission a dozen times to troubleshoot an issue. PURT accelerated our progress and gave us the tools, space and resources to accomplish our deliverables for the project."

The Study

To conduct the study, held in fall 2022 at the Alexander Field baseball stadium, the researchers recruited medically naïve student participants who had never been inside an ambulance, did not know anyone who had overdosed and had very little medical experience. Participants were not told there would be a medical emergency, only that they would be interacting with a drone. A nursing student portrayed a panicked bystander to create a sense of urgency around the situation. The study participant would simulate calling 911 to report the emergency, prompting the team to launch the drone. The entire process was videotaped and analyzed to determine the exact amount of time each step took.

"We needed to know exactly how long it took for the participant to reach the drone, how long to remove the medication, how long to walk back to the victim, how long to administer the medication," Adams says. "Every second counts in a medical emergency and knowing how much time is needed on the scene informs how quickly the drone needs to arrive once the emergency is called in. That information will help engineers calculate flying distance, how robust the drone needs to be, how fast it needs to travel and whether delivery of the instructions is clear and efficient."

The RUN team operated the vehicle and used its autonomous features to create a repeatable mission plan. The human participants in the study provided the team with valuable feedback on the prototype's ergonomics. One user yanked out the primary computer that controls the drone's flight, mistaking it for the container holding the medication, but all users successfully completed the task.

The average total time to remove the Narcan from the drone and administer it to the victim clocked in at 62.65 seconds. Although it was a small pilot study, the results are promising and publication of the research is pending. Still, the students continued to refine the design during the spring 2023 semester.

"A big part of the engineering process is querying stakeholders about their needs and then deriving more specified engineering requirements so we can design to those requirements," Lundin says. "After the human trial, we upgraded the propulsion system of the vehicle and conducted some studies to understand how that would affect performance. We also reworked how the computers, video screen and Narcan payload fit into the vehicle. The new solution should be much easier for individuals to operate."

The Next Giant Leap

A group of Purdue researchers are now in the process of applying for an $80 million midscale infrastructure grant from the National Science Foundation to build the world's first outdoor research facility for UAVs. The UAV runway and testing area would have the same kind of motion capture sensing as PURT, just outside.

"An outdoor facility would enable us to test out the feasibility and application of the RUN project in a full-scale, realistic setting," Kong says. "Beyond that, there are so many possible applications, just within the field of health care. Many other public health services could be augmented by drones including supply of blood, medicine, vaccines and other critical health commodities as well as field-triage of traumatically injured patients in mass casualty.

"The vision of an outdoor UAV research facility is well-aligned with Purdue's mission as a land-grant institution to improve the social and economic status of the region. The application of drone technology is only going to expand and Purdue engineering students are poised to lead the next giant leap in innovation."

THE OPIOID CRISIS

Drug overdose deaths are at an all-time high in the U.S. and Indiana is no exception. Overdose deaths in the state have doubled over the past decade.

107k

PEOPLE NATIONWIDE DIED OF AN OVERDOSE

2,751

INDIANA RESIDENTS DIED OF AN OVERDOSE

70%

OF INDIANA'S OVERDOSE DEATHS WERE CAUSED BY FENTANYL AND OTHER SYNTHETIC OPIOIDS

2022 data from the Centers for Disease Control and Indiana Department of Health

WEATHER REPORTS FROM THE SKY

Commercial airlines have excellent weather information. Why don't private pilots?

To better understand the causes of weather-related accidents in general aviation, Professor Barrett Caldwell studied how well people in that community understand lags in weather data.

PURDUE UNIVERSITY PHOTO/ALAN CESAR

There's a weather data problem in general aviation, and it's costing some private pilots their lives. Barrett Caldwell, professor of industrial engineering and aeronautics and astronautics, says the weather and navigation technologies themselves have advanced significantly — but they don't align with pilots' expectations. He came across this information while working on a research project for the FAA Weather Technology in the Cockpit program office.

"People often believe the data you see on a weather radar represents right now. But it can be delayed by 15 minutes or more. The life of a thunderstorm cell might be 20 minutes, so it might not appear on weather radar until it's over," he says.

He identified several sentinel incidents where a lag in weather information factored into an accident, and likely led to a pilot's or passenger's death. That motivated him to dig further.

His research group designed multiple projects to see how well people in the general aviation community understand that data lag. They put together a demonstration and brought it to several major aviation gatherings, like the EAA Airventure show in Oshkosh, Wisconsin, and Sun 'n Fun in Lakeland, Florida, to see what decisions pilots make in certain flying situations.

Office Hours with Barrett Caldwell

Hear the Philadelphia-born professor's subtle sense of humor and learn why he keeps little bear figurines around.

Watch the College of Engineering's video series, Office Hours, at youtube.com/PurdueEngineering.

"We saw pilots get trapped because of uncertainty, latency and poor awareness of weather dynamics," he says.

Part of the problem is a lack of pilot reports (PIREPs) in general aviation. Commercial airlines have a great reporting record, Caldwell says. "When you hear the pilot on an airliner say, 'We've got reports that it's going to be bumpy,' that's often coming from a PIREP, which might even be automated from other commercial aircraft. But we don't have that for general aviation."

PIREPs are harder to do for pilots in smaller aircraft, especially in single-seaters with no one to help with the controls. But those smaller aircraft are also more susceptible to winds and weather.

As lead of the Enhanced Hands-Minimized Interfaces project, Caldwell's team has been working on a system can translate speech into properly coded PIREPs. This project is part of the FAA's PEGASAS, the Partnership to Enhance General Aviation Safety, Accessibility and Sustainability — a Purdue-led multi-institution effort.

One challenge with training an AI language model is having enough training data, something Purdue is working with Florida Tech to collect. That voice recognition system will also need to deal with a lot of background noise, plus the usual challenges of natural language processing. Initial tests have been positive, and they're moving forward with additional funding.

"I don't believe in finding an 'ideal box' to fix the problem. There are apps all over that give you weather info," Caldwell says. "A lot of pilots already have a comms system like Garmin, Flight Aware or something else in the cockpit. It would be great if those systems could have a button to file a PIREP."

Caldwell hopes, if he can make the reporting process easier, pilots can be better prepared before every takeoff — even if it's just for a quick hop to the nearest FBO diner.

PEGASAS has been awarded $40.4 million in a combination of FAA funds and matching support for 34 projects since its founding in 2012. Purdue has participated in 22 of those projects, totaling $13.7 million.

More on this program at pegasas.aero

Online safety design training for working engineers

A new online course at Purdue is filling a gap in safety design education. Based on a request from industry, Karen Marais, professor of aeronautics and astronautics, is showing engineers how to make safe design an integral part of their process.

"We need to work against the 'safety guys are spoiling the fun again' mindset. If we think about safety from the beginning, it's much easier to do it well, rather than finish the design and say, 'Okay, how now do we make this safe?'" Marais says.

Thinking ahead to potential safety problems can reduce costs and give better results. Adding redundancy doesn't help if, for example, both engines have the same defect. Though the course is based on civil aviation processes, the methods taught can apply to any system, from submarines to rockets.

Marais gave this course maximum flexibility for working professionals. "We've taken it to a whole new level. There are no in-class presentations. It's completely online, asynchronous and self-driven. And unlike many continuing education courses, students receive individualized feedback on their assignments. This approach helps them to really engage with the material in a way that's hard to do when you just watch a series of lectures."

The course, Principles and Methods of Safe Aero System Design, can also be taken for college credit. Sign up in summer 2024 at **online.purdue.edu**.

PURDUE UNIVERSITY PHOTO/JOHN UNDERWOOD

MATERIALS WITH TOUCH

With two major early-career grants, Tyler Tallman is breathing new life into the self-sensing materials field

Tyler Tallman, associate professor of aeronautics and astronautics

PURDUE UNIVERSITY PHOTO/ ALAN CESAR

Research into self-sensing materials had begun to stagnate when Tyler Tallman was publishing his first papers in 2013. Back in the early 2000s, the field was abuzz about materials like carbon nanotube polymers, which would change their electrical properties when deformed. These materials showed potential to revolutionize structural sensing: Instead of mounting strain gauges at certain points, structures could be painted with or made of self-sensing materials.

By combining that feature with ongoing experiments in electrical tomography, engineers dreamed of a spaceship with skin-like sensitivity: A ship's tomography map could show the pilot if her ship was bending, stretching, damaged or worse. No individual sensors required.

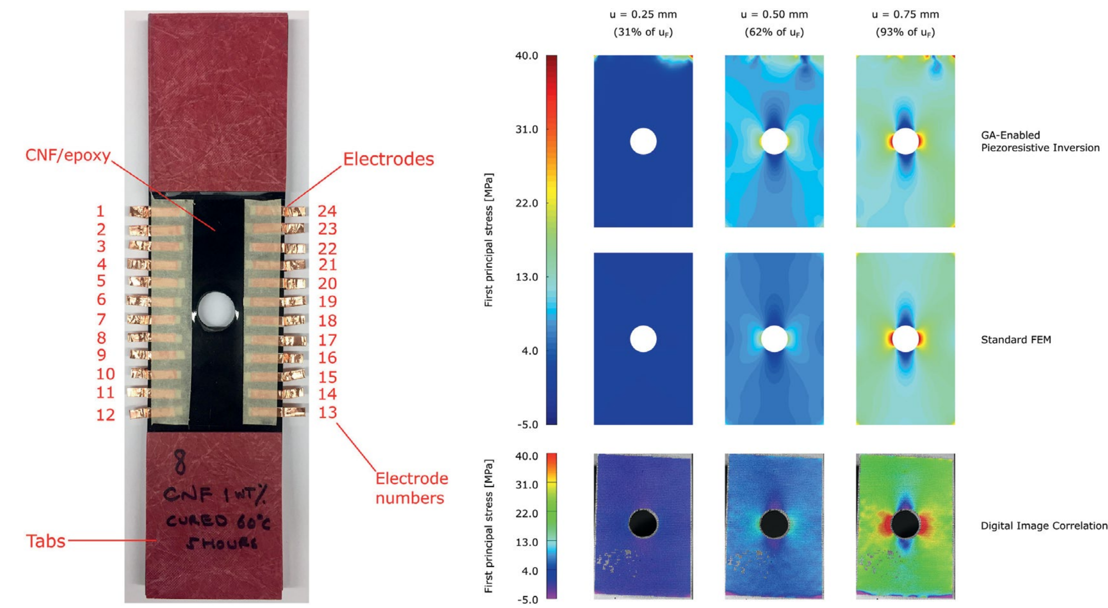
But Tallman, associate professor of aeronautics and astronautics, says the field didn't make significant moves beyond those foundational experiments. The dream was going stale.

"There were still so many papers doing the exact same thing they did more than two decades ago. Research sponsors are not interested in studying flat plates with through holes or other overly simple conditions. They want to know how we advance this technology to realistic shapes and realistic conditions," Tallman says.

"And then we have to say, 'Well, what can we actually do this with information?' Structural engineers are not interested in electrical properties. They want to know stresses, strains, damages, things like that. Mechanical properties. I think that's been where we have made the most contributions in our research group."

Tallman credits Hashim Hassan (MSAAE '17, PhD AAE '21), now a visiting assistant professor in AAE, whose thesis at Purdue helped couple the relationship between electrical properties and mechanical condition. Tallman's group extended that to a variety of materials and are looking at more complex shapes like airfoils, tubes and truss structures. He completed several papers in collaboration with the Air Force Research Laboratory (AFRL) on these topics.

"We're moving past simple specimens, moving past flat plates and looking into how we actually transition this into practice," he says. "I think that's what's attracting the attention of sponsors like the Air Force: We are trying to move this technology away from just being an academic curiosity and into meaningful practice."



This electrical impedance tomography (EIT) experiment conducted by Tyler Tallman and Hashim Hassan shows conductivity change distributions in a specimen that is under tension. Tallman is finding the correlation between the conductivity change and the physical effects.

Adding a fourth dimension to 3D printing

Tyler Tallman, together with associate professors Brittany Newell and Jose M. Garcia-Bravo in the School of Engineering Technology, produced a patent-pending wet-mixing method to evenly add particles to filament used in 3D printers.

"A limitation of application of 3D printed parts has been in their durability," Newell said. "With this development, we can continually monitor the structural health of the part with the sensor embedded in the print."

CAREER and YIP awards

Tallman's contributions have attracted serious interest: A three-year, $445,000 grant from the Air Force Office of Scientific Research's (AFOSR) highly competitive Young Investigator Research Program (YIP) supports his proposal on data fusion. The funding has helped him bring on several grad students to explore the challenge of combining information from many different inputs, extending it specifically to 3D-printed polymer matrix composite materials with self-sensing properties.

It's interdisciplinary work, which energizes Tallman: "It requires understanding how electrical properties can be embedded in 3D-printed materials, how those electrical properties change with evolving loads, and the inverse mathematics needed to correlate the electrical changes with physical state changes."

His second grant in 2023, worth $510,000 over five years, is more foundational. The National Science Foundation's (NSF) Faculty Early Career Development (CAREER) program supported his proposal to dig deeper into what Hassan showed. The results could extend to many materials that exhibit conductivity-deformation coupling.

"By inverting the relationship between electrical changes and mechanical loading in these materials, it is possible to know the full-field mechanics from only a small number of electrical measurements. This research will discover the basic nature of this inverse problem, which will lead to more accurate, more robust and faster solutions," he says.

Tallman adds that this technology could also be used in fields like biomedicine, robotics and geospatial imaging.

Eliminating barriers to women in STEM

With service as a key component of the NSF's CAREER grant, Tallman wanted to use this platform to support women and girls interested in STEM. He has seen how difficult it can be for women trying to succeed in male-dominated fields: His wife, an orthopedic surgeon, faced frequent harassment during her residency training.

"It was just nonstop — from subtle, culturally entrenched things to some grossly overt stuff, not just to her, but to many of the women in her program," he says. "Through all that, she mentioned that having mentors and allies was a thing that really helped her."

When he came to Purdue, Tallman wanted to contribute to programs that offer that support. He approached the Society of Women Engineers (SWE) about bringing aerospace-themed activities to their Girl Scout Day program.

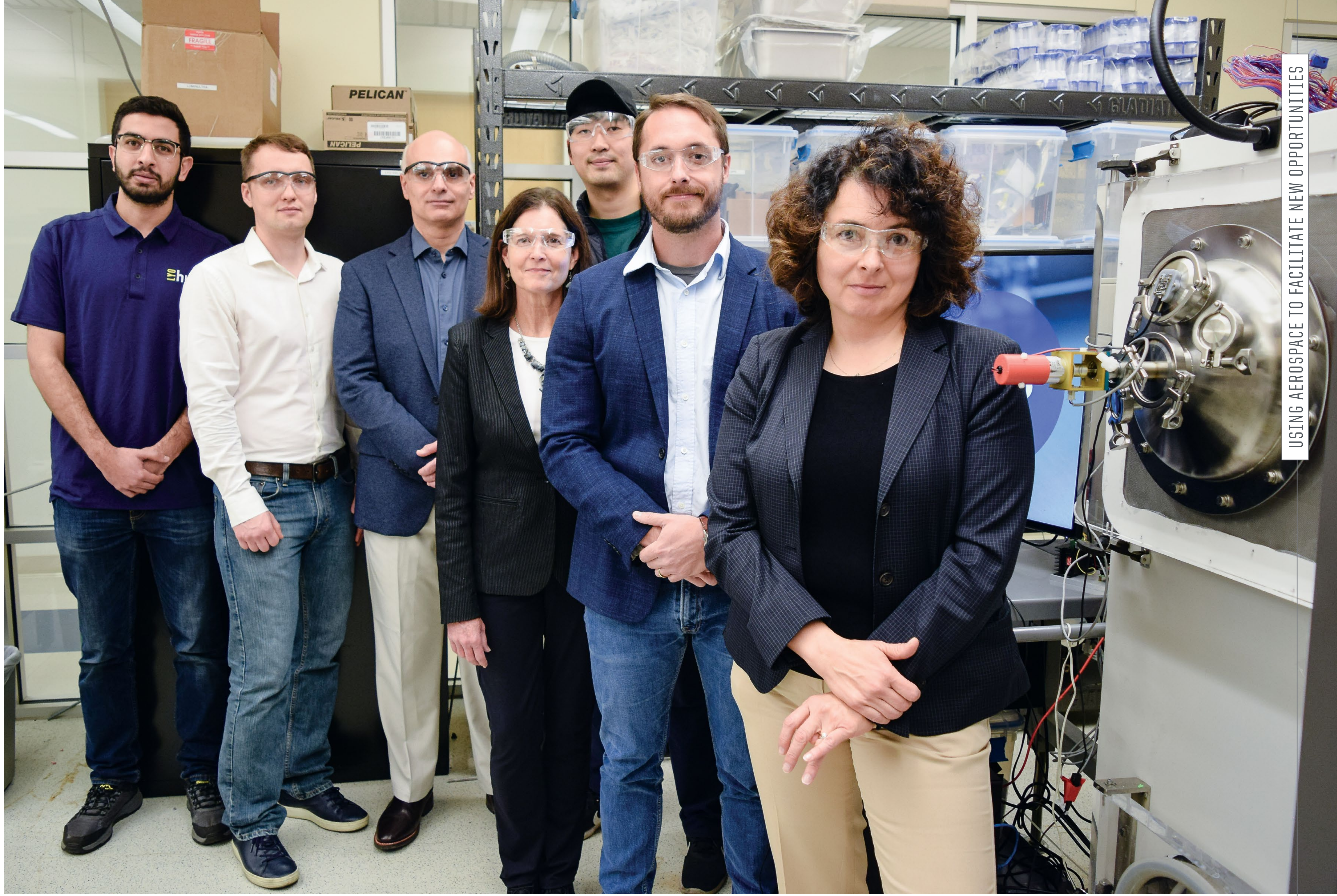
"He expanded his engagement in outreach to girls through the Women in Engineering (WiE) program," says Beth Holloway, director of WiE and professor of engineering practice in mechanical engineering. "We've continued to work with Tyler because of his positive attitude and his dedication to outreach. He is exactly the kind of faculty partner that WiE needs and appreciates!"

Tallman's NSF proposal included partnering with SWE and WiE to integrate self-sensing mechanics with additional outreach activities in the greater Lafayette area.

"The goal is not to turn every outreach student into an engineer," he says. "Although that would be fantastic, we just want them to feel like it's okay for them to study engineering. There should be no barrier to it just because you're not a guy."

USING ROCKET SCIENCE FOR FASTER VACCINES

PURDUE RESEARCHERS ARE WORKING TO BRING NEW FREEZE-DRYING METHODS TO MARKET, POTENTIALLY SLASHING TRANSPORTATION COSTS.



Members of the LyoWave and LyoHub teams stand next to their device, a microwave emitter developed at Purdue that vastly reduces the time needed to freeze-dry vaccines and other pharmaceutical products.

From right to left: Alina Alexeenko, AAE professor; Drew Strongrich, AAE alumnus and LyoWave CEO; Kyu Yoon, research scientist; Jennifer Gray, operations manager at LyoHub; Dimitrios Peroulis, professor of electrical and computer engineering; Petr Kazarin, postdoctoral researcher; and Ahmad Darwish, senior research associate.

Freeze-drying is as costly a process as it is important. Though it can take days or weeks to properly freeze-dry a product, it's nonetheless critical to manufacturing for the pharmaceutical industry. Freeze-drying, or lyophilization, is used in about 25% of new injectable drugs, vaccines and biological products, in addition to certain food products.

That cost and technological complexity makes some treatments inaccessible in many parts of the world. Purdue researchers have been trying to change that.

Alina Alexeenko, professor of chemical engineering and aeronautics and astronautics, and her team at LyoHUB could be close to a solution. In September 2021, the National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL) awarded the team nearly $1 million to pursue technology that could make the freeze-drying process twice as fast and more cost-effective. That technology, now patented, is nearly market-ready.

A rocket scientist among pharmaceutical engineers

Alexeenko may be the reason people in lyophilization compare their work to rocket science. She was introduced to the field in 2007, when an engineer in the Netherlands emailed her about the computer code she'd written on the viscosity of a very cold, low-pressure mixture of water and nitrogen.

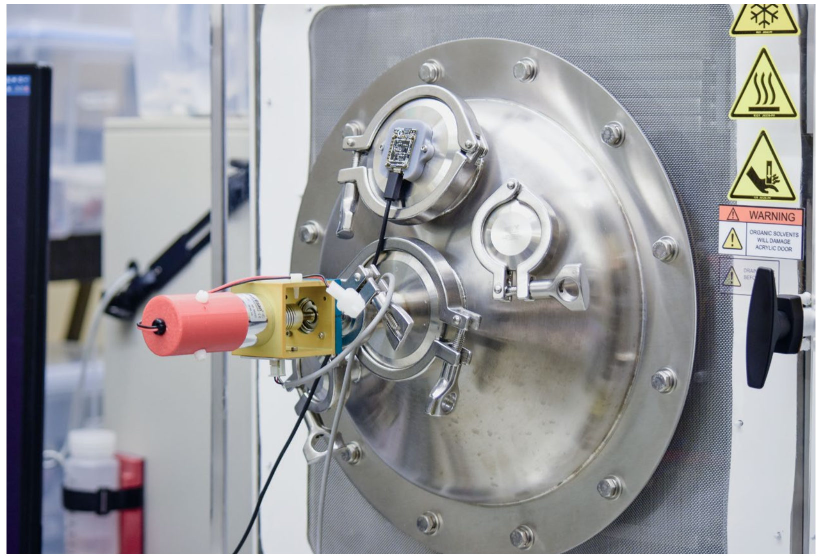
"I asked why he is interested in that, because that's a very strange set of conditions. Turns out he was working on freeze-drying," Alexeenko says.

That was enough to pique her interest.

Through her mentor John Sullivan, professor emeritus of aeronautics and astronautics, she connected with lyophilization expert Steve Nail (BS ChemE '72, PhD Pharmacy '75). At the time, Nail was a research scientist with Baxter Pharmaceuticals. She quickly saw the overlaps between their work and they began collaborating.

"Everything about freeze-drying is challenging," Alexeenko says. "It involves the entire textbook of fluid dynamics — multiphase, viscous, porous, compressible and rarefied flows are encountered in various parts of the system. As a fluid dynamicist, I am fascinated by that complexity."

The conditions inside a freeze-dryer are similar to Earth's atmosphere more than 80 kilometers up: It's extremely cold, and the air pressure is extremely low. The usual rules for how fluids behave



This device is a prototype of the microwave generator that LyoWave is preparing to bring to market. It is sized to fit on standard freeze-drying cabinet doors, which makes it easy for pharmaceutical companies to incorporate this technology into their existing manufacturing processes.

Drew Strongrich (left) and Ahmad Darwish review circuit diagrams for a simple control module that would replace the cabinet of electronic equipment driving the prototype microwave lyophilizer.

don't apply anymore. Alexeenko's expertise is in rarefied gas dynamics, a field developed for space exploration. All her computational analysis and design methods apply directly to lyophilization.

Within a year of that first email, Alexeenko was giving a talk at a lyophilization conference. By 2014, working closely with Elizabeth Topp, a professor in Purdue's Department of Industrial and Physical Pharmacy, Alexeenko became a co-founder and co-director of LyoHUB, a university-industry center for improving freeze-drying technology.

"LyoHUB includes over 30 industry members now. Many of them are direct competitors, but they work together in a very collaborative environment to advance this technology. This led to first technical standard in lyophilization, issued by ASTM in 2021; the first technology road map; and many other small steps to improve the technology that is at the core of making modern diagnostics, medicines and vaccines," Alexeenko says.

"I call it the least-known of the most important technologies of the 20th century."

Heating up in low density

The traditional lyophilization process involves freezing, then drying. Once the product has been super-cooled, a little energy is added back in to encourage trapped ice to sublimate — to skip the liquid phase and convert directly from a solid to a gas, allowing it to escape.

But heat doesn't transfer easily in a near-vacuum. In a lyophilizer, racks of product are touching shelves that are cooled or heated by circulating a fluid like silicone oil through them. Not only is this slow and energy-intensive, it can lead to inconsistent results across large batches.

Alexeenko and her team have been working to improve the use of microwave energy to do the heating portion. Microwaves can travel easily in a vacuum. They also heat any trapped moisture at the molecular level, making the heating portion of the process near-instantaneous. Temperature sensors on the product can be used in a feedback loop to control the heating.

The main difference between these microwaves and the kitchen variety is the frequency: Home microwaves run at 2.45 GHz whereas these are tuned to around 18 GHz, which the team determined is more effective at heating ice. Another critical feature of the Purdue technology is producing highly uniform heating. Regular microwave use a turntable to counteract hot spots. The team flipped this idea and found a way to rotate the electromagnetic field in random directions, while the biopharmaceutical product remains stationary.

Ahmad Darwish, a senior research associate, removes a tray of vials from a freeze-drying cabinet that has been fitted with a microwave heating device developed at Purdue.

Partners and progress

LyoWave Inc., Alexeenko's startup company, is working with the Purdue Innovates Office of Technology Commercialization to bring their patented RF/microwave lyophilization technology to market.

"Freeze-drying increases the shelf-life of our most important and life-saving medicines from a few days to months or even years. That's obviously a great thing, but the hard truth that pharmaceutical companies have to face is that it's also slow, risky and expensive," says LyoWave's CEO Drew Strongrich (BSAAE '13, MSAAE '15, PhD AAE '21). "The growing demand for these products combined with limited global production capacity means that we could soon hit a bottleneck. The industry has been looking for a solution to this problem for a long time."

Their million-dollar grant from NIIMBL came through their Global Health Fund, established by the Bill & Melinda Gates Foundation.

Who's Who in RF/Microwave Lyophilization?

The Purdue research team includes:

ERIC MUNSON
Industrial and Physical Pharmacy

VIVEK NARSIMHAN
Chemical Engineering

DIMITRIOS PEROULIS
Electrical and Computer Engineering

QI (TONY) ZHOU
Industrial and Physical Pharmacy

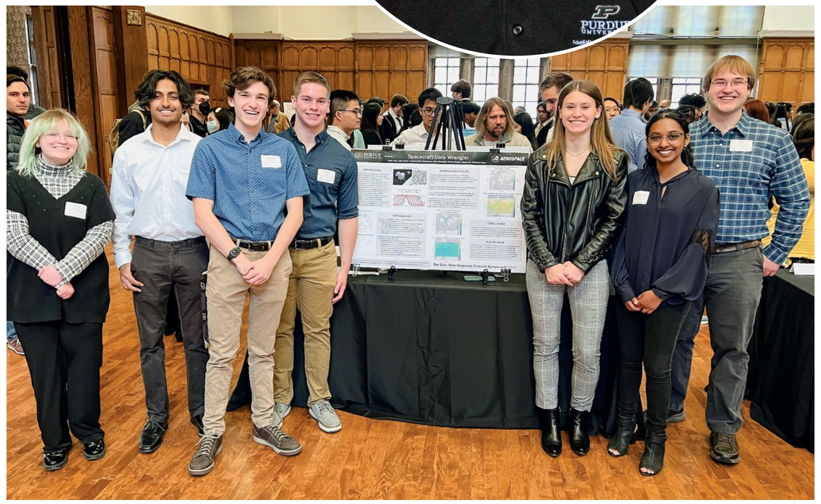
Pharmaceutical companies Merck and IMA Life North America have partnered with Purdue on the project, providing tools to bring it to life. Merck is sharing vaccine samples and developing benchmarks to compare microwave lyophilization with the conventional method. IMA Life will integrate the new technology with the entire manufacturing process for sterile pharmaceuticals and vaccines.

"This microwave technology promises to not only provide uniformity to the drug product but also accelerate the freeze-drying process," says Ernesto Renzi, president of sales and marketing at IMA Life.

Karen Plaut, Purdue's executive vice president of research, touts this significant technological advancement as one of the ways the university is able to make a difference. "Centers like LyoHUB are a great example of how we draw upon Purdue's deep research strengths and state-of-the-art facilities, and leverage the expertise of industry and government to improve our world."

MAX DATA

COLLABORATIVE PROGRAM BRINGS DATA ANALYTICS TO ALL MAJORS



Max Low has been living and breathing data science for four years. He's now a master's student in aeronautics and astronautics, but when he was exploring the housing options available at Purdue, his main hope was to be steeped in knowledge.

As soon as he saw the Data Mine, housed at Hillenbrand Hall, the choice was clear.

"I knew I wanted to find a sense community when starting college, and a learning community provides an excellent networking opportunity right off the bat. It appealed to me as I had heard data science was an up-and-coming field and it could help me stand out," Low says.

The Data Mine is Purdue's first large-scale learning community for undergraduate and graduate students. What began as a 100-student pilot project in 2018 has now grown to more than 1,700 students across 20 learning communities. AAE students are one of the largest cohorts, but they encourage interdisciplinary collaboration and welcome students from all majors, no computational background required.

"The best part is the practical industry experience," Low says. "Nowhere else did I see the opportunity to just go straight into a research project with top companies in my field where they would teach me the prerequisite knowledge."

More than 60 companies have partnered with the Data Mine to teach the data analysis skills they and graduate programs are seeking. Companies provide a mentor to each team. Lauren Dalder, a corporate partners advisor specializing in aerospace, is coordinating 17 of those projects this academic year.

"There's an intangible thing about going to a university, and that's the knowledge-sharing. That's something we get by working together. Data Mine builds that into a class schedule," Dalder says. "Students gain exposure to all these things that are possible with their AAE degree. They register for this class and go work with Howmet, Lockheed Martin or another corporate partner for the whole year. There's not a job application, they just get the experience."

DATA MINE DIGS DEEPER

The Data Mine is part of Purdue University's Integrative Data Science Initiative, designed to train students across all majors in data literacy. In 2021, Purdue took the concept statewide with $10 million in funding from the Lilly Endowment, creating the Indiana Data Mine. It aims to create a statewide ecosystem where students learn data science through hands-on projects with corporate partners.

Bringing Aerospace Home

Dalder heralds Low as their biggest success story. He mentors younger students and is a warm presence in the Data Mine office. Low even earned them a corporate partner in The Aerospace Corporation: "Aerospace was so impressed by Max that when they interviewed him for an internship, that's how they became interested in the Data Mine," Dalder says.

With that partnership, Low led a project on how to remove noise from spacecraft telemetry data, and merge the telemetry types reported by various spacecraft. He says it helped him gain some intuition about how to analyze telemetry data, and showed him how complex it can be to aggregate spacecraft data.

"This project reinforced my project leadership skills. As the project lead it's important to have strong communication skills, clear project goals and deliverables, and timely communication with your team and customer," Low says.

At his internship this summer, that experience was on full display.

"My work at Aerospace incorporated all of my skill sets. A successful engineer is an amalgamation of many different skills. I use my aerospace, data science and project management skills, which I built at Purdue, daily."

USING AEROSPACE TO FACILITATE NEW OPPORTUNITIES

CYBER-SECURE AEROSPACE

NEW COURSE MEETS WORKFORCE NEED FOR SYSTEMS THAT ARE DESIGNED SAFE FROM CYBERTHREATS

Now in its second year, the first aerospace cybersecurity course of its kind is giving AAE students valuable hands-on experience in cyber-domain security. By partnering with computer science and cybersecurity majors on a real-world problem, this interdisciplinary course teaches collaboration, teamwork and perspective on the cybersecurity challenges unique to aerospace.

"In a traditional IT mindset, we think of 'assets on the network are at risk,' and we'll put a devices in to add a layer of security to guard against intrusion, or a 'hack'," says Joel Rasmus, managing director of the Purdue Center for Education Research in Information Assurance and Security (CERIAS).

"In an airplane or other transportation system, you're governed by power, space, weight. The more space we take up, or weight we add, the more power we will need. The idea of adding another security device doesn't work. It takes away seats on a plane or adds weight."

This new Purdue Aviation and Space Cybersecurity program is not meant to turn aerospace engineers into cybersecurity professionals or vice-versa — both groups of students are broadening their skill sets and lining themselves up to be better employees in the aerospace industry. They come out thinking about how to find solutions that are secure by design, rather than treating security as an afterthought or an "add on" feature.

The program was made possible through the Data Mine's infrastructure. The idea was to get students from different disciplines working together on a specific industry problem and, while solving it, they would teach each other about their domain-specific constraints. That matched up with how the Data Mine runs their corporate partners program.

"It's been a home run. Boeing has offered internships and jobs to many of the students involved because they're so far ahead of their peers," Rasmus says. "Immediately we had other commercial and government industry partners asking for something like it."

For year two, Rasmus is adding more guest speakers working at the intersection of aerospace and cybersecurity. Other companies, including several U.S. Department of Energy national labs, Rolls-Royce and Raytheon, are interested in teaming CS and cybersecurity students with domains like nuclear or mechanical engineering to address the growing cyber risk to physical systems.

UNIVERSITY NEWS

Arvind Raman takes over as College of Engineering dean

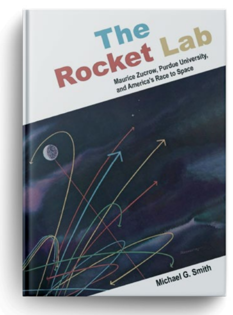
Longtime Purdue administrator and faculty member Arvind Raman is the new John A. Edwardson Dean of the College of Engineering. Raman was executive associate dean for four years before stepping into the role on April 1, 2023, replacing interim dean Mark Lundstrom. Lundstrom continues to lead semiconductor activities across the university and serve as the Don and Carol Scifres Distinguished Professor of Electrical and Computer Engineering.

Purdue announces $1.3 billion in facilities investments

In July 2023, the university issued a snapshot of recently completed, ongoing and planned capital projects totaling more than $1.3 billion. These investments are taking place alongside the approved 11th and 12th consecutive years of frozen tuition. Work includes new student housing, renovations to the mechanical engineering building and Ross-Ade Stadium, and new construction at Zucrow Labs.

Also in the plan are runway improvements and a new passenger terminal that could bring commercial air service back to Purdue Airport. The 8,000-square-foot facility — to be located west of the existing terminal — will include baggage claim, ticketing and passenger screening and meet TSA and FAA requirements. Construction is scheduled from May 2024 to May 2025.

Visit **purdue.edu/physicalfacilities** to see the Major Capital Projects map.



THE ROCKET LAB

Purdue University Press has published *The Rocket Lab: Maurice Zucrow, Purdue University, and America's Race to Space*, by Michael G. Smith.

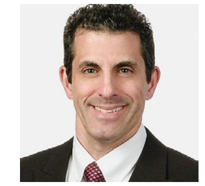
It covers the life of Maurice J. Zucrow during the golden era of space exploration — 1946 to 1966. It is available in paperback, hardcover and digital versions at **press.purdue.edu**.

STUDY ABROAD PROGRAM CELEBRATES ITS 20TH ANNIVERSARY

In May 2023, many of the people who participated or were involved in Purdue's Global Engineering Alliance for Research and Education (GEARE) program gathered in Karlsruche, Germany, for a 20th anniversary reunion. Karlsruche Institute of Technology has partnered with GEARE since 2003 to provide a work experience, cultural training and a team-based design project. Nearly 1,000 Purdue students have participated in the program.

Find a full story with videos at **bit.ly/geare20**.

ALUMNI NEWS



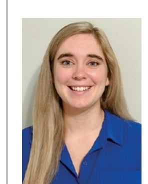
Darin DiTommaso (BSAAE '88, OAE '20) is now vice president of engineering for GE Edison Works.

Tony Gingiss (BSAAE '90, OAE '19) joined Terran Orbital as its chief operating officer. The company is a global leader in satellite-based solutions.

Erika Pearson (BSAAE '93) became Boeing's vice president of commercial sales and marketing over South-east Asia and Oceania.

Yen Matsutomi (BSAAE '03, MSAAE '05, PhD AAE '09, OAE '20), vice president of engine design at Blue Origin, received the Career Achievement Award from the Society of Asian Scientists and Engineers.

Natalie Smith (MSAAE '11, PhD AAE '15) earned the Dedicated Service Award from the American Society of Mechanical Engineers. She is a group leader in rotating machinery dynamics Southwest Research Institute.



Amy Comeau (BSAAE '18) was named a 20 Under 35 by Space & Satellite Professionals International for 2023. She is a lead member of the CST-100 Starliner Chief Engineer's Office at Boeing.

Vivek Muralidharan (MSAAE '17, PhD AAE '21), a post-doctoral researcher at University of Luxembourg, made the list in 2022.

Six alumni inducted as Outstanding Aerospace Engineers

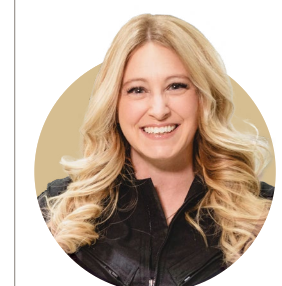
Purdue AAE awarded six alumni who have demonstrated excellence in their work reflecting the value of an aerospace engineering degree.

The honor of 2023 Outstanding Aerospace Engineer (OAE) was presented to (left to right) Steven Wanthal (BSAAE '85, MSAAE '87, PhD AAE '89); Scott Claflin (MSAAE '87); Cyrus Sigari (BSAAE '03); James Winkelman (BSAAE '92); Sirisha Bandla (BSAAE '11), 2022 awardee; John Tsohas (MSAAE '05, PhD AAE '09); and Cynthia Mahler (BSAAE '98), not pictured.

Distinguished Engineering Alumni

Three AAE graduates received the Purdue College of Engineering's highest alumni honor, the Distinguished Engineering Alumni (DEA) award. Alumni must first receive the school's OAE award to be eligible for DEA. The 2023 recipients are:

- **Julie A. Kramer White** (BSAAE '90, OAE '17), director of engineering at NASA Johnson Space Center
- **James P. Renna** (BSAAE '86, OAE '10), retired chief engineer for Sikorsky Aircraft
- **J. William Uhrig** (BSAAE '82, OAE '14) president and managing partner of Three Cities Research



Alumna Beth Moses completes three suborbital flights in as many months

Beth Moses (BSAAE '92, MSAAE '94, OAE '18), chief astronaut instructor at Virgin Galactic, led three groups of space tourists on commercial suborbital flights aboard the company's VSS Unity ship — one flight each in August, September and October 2023. Moses was also on an all-employee launch in March, bringing her total trips to space up to six.

Send your news and updates to aae@purdue.edu or tag @PurdueAeroAstro on LinkedIn, Instagram, X or Threads.

FACILITY NEWS

Purdue Applied Research Institute opens $41M Hypersonics and Applied Research Facility

On June 6, 2023, leaders from federal government and industry joined leadership and staff from Purdue University and the Purdue Applied Research Institute (PARI) in celebrating the official opening of the Hypersonics and Applied Research Facility (HARF). This 65,000-square-foot building is home to two cutting-edge wind tunnels, plus the Hypersonics Advanced Manufacturing Technology Center (HAMTC) led by Michael Sangid, the Reilly Professor of Aeronautics and Astronautics.

At HAMTC, industry partners can work on materials and manufacturing innovations in a single location, with access to high-tech testing capabilities. “HARF is an investment in test and evaluation and research capabilities that this country desperately needs,” said Mark Lewis, chief executive officer for PARI.

Cutting the ribbon at the grand opening of the Purdue Hypersonics and Applied Research Facility are (from left) Karen Plaut, executive vice president for research; Mark Lewis, CEO of PARI; Mung Chiang, Purdue University president; Scott Meyer, managing director of Maurice J. Zucrow Laboratories

PURDUE UNIVERSITY PHOTO/CHARLES JISCHKE

Images like this one were downloaded from Lightsail 2 through Purdue’s antenna and ground station. PHOTO COURTESY OF THE PLANETARY SOCIETY

AAE satellite antenna restored for DBF courses

ANTENNA SPECS
550 watts max
43db gain
9600 baud bandwidth
430 mhz

A satellite communications antenna has been restored and relocated to the roof of Armstrong Hall, from its previous location atop the off-campus Purdue Technology Center.

Tony Cofer, spacecraft laboratory engineer for AAE, refurbished its cables and motors and made other repairs in recommissioning it. “We can theoretically put out 550 Watts, though I don’t like to push it over 400,” Cofer says. “This one was made to track and download data from Lightsail 2.”

Lightsail 2 was a citizen-funded project, designed by Purdue researchers and launched by The Planetary Society to test solar sail propulsion technology. “Most of the images it captured were downloaded through our antenna and ground station,” Cofer says.

Now that it’s operational again, the antenna will communicate with the FEMTA-enhanced Laser Communications Satellite (FLaC-Sat) and Aerodynamic De-orbit Experiment (ADE), both of which are part of design-build-fly courses in the Vertically Integrated Projects program in AAE.

New lab spaces, more hands-on time

Over the summer of 2023, the School of Aeronautics and Astronautics gained access to an additional 4,415 square feet of lab space in the basement of Armstrong Hall. Aerodynamics and fluid mechanics labs total more than 400 students spread across multiple sessions, says Sally Bane, director of laboratory and hands-on education and associate professor of aeronautics and astronautics. Moving her lab equipment to room B098 has been great for her students.

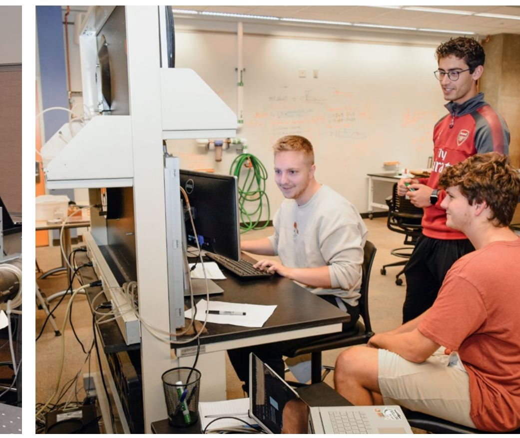
“In our previous space, we had one low-speed wind tunnel, one water tunnel and one supersonic tunnel for hundreds of students to use,” Bane says. “This new lab space allows us to have two or even three copies of each experiment, so now the students can have more time interacting hands-on with the equipment in smaller teams. We can accommodate our exploding undergraduate enrollment while still providing a high quality, hands-on learning experience.”

AAE is the fastest-growing school in the College of Engineering, breaking undergraduate attendance records year-over-year since 2015. Professor Art Frazho’s control systems lab, now adjacent to Bane’s in the new space, supports more than 200 students.

Professor Steven Collicott, who teaches about 100 students in the team-based Zero Gravity Flight Experiments course, has been able to move that operation to a larger lab that Bane vacated. “This shift to room 3098 provides more floor space, which is greatly appreciated. It begins to address the needs of the very large enrollment that AAE’s decades of successes have generated.”

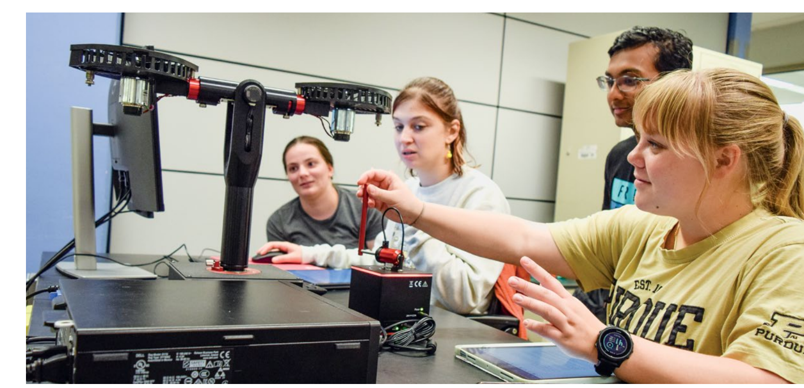
Financial support to move equipment and build out these lab spaces came from strategic initiative funds, which are provided by the Purdue for Life Foundation on behalf of the University’s loyal donors.

AAE instruction manager Chell Nyquist spearheaded the project, coordinating the necessary construction, wiring and plumbing work to revamp the space and the logistics of moving sensitive lab equipment. In December 2022, Nyquist received the Professional Achievement Award from the College of Engineering. “Chell is worth his weight in gold,” says April Sauer, AAE operations manager.



AAE makes room for Maker Space

In fall 2023, AAE secured space for student projects at the Purdue Technology Center. It will be outfitted with fabrication equipment and other tools that student clubs can use to prepare for collegiate competitions.



FACULTY NEWS

NEW FACULTY

AAE has hired several new faculty members to keep up with the program's tremendous growth. Below are the new faces joining us this academic year. Look for feature stories coming to the AAE website.

Associate Professor

Kawai Kwok comes to Purdue from the University of Central Florida, where he researched viscoelastic and tubular ceramic materials; self-deployable structures; and porous metals in solid oxide fuel cells. He was also a research scientist at Technical University of Denmark, and has a PhD from CalTech. His research interests are in aerospace structures, materials and dynamics.

Assistant Professors

Kazuki Maeda previously collaborated with Purdue on laser-based ignition through his large-scale turbulence simulation work at Stanford. His research interests are in rocket propulsion, hypersonics and data assimilation. He has a PhD from CalTech.

Andrea Capannolo did postdoctoral research at ISAE-Supaero on phasing and rendezvous strategies for the Lunar Gateway. He's interested in orbital dynamics and guidance, navigation and controls, especially in multi-gravity environments like cislunar space. He earned his degrees at Politecnico di Milano, Italy.

Associate Professors of Engineering Practice

A Purdue AAE graduate, **Jamie Canino** returned to campus to teach and mentor AAE undergraduates. He comes from 13 years on the faculty at Trine University, including standing up their Center for Teaching Excellence.

Thiago Guimarães was a structural stress analysis engineer at Embraer. After earning his PhD at Federal University of Uberlandia in Brazil, he worked as research scientist on NASA's SCALOS project through the University of Michigan.

Research Assistant Professor

Zherui Guo was a distinguished postdoctoral researcher at the Idaho National Laboratory. His multi-disciplinary research combined impact dynamics, solid mechanics, composites science and advanced materials characterization. He earned his BS, MS and PhD from Purdue AAE.

Visiting Assistant Professors

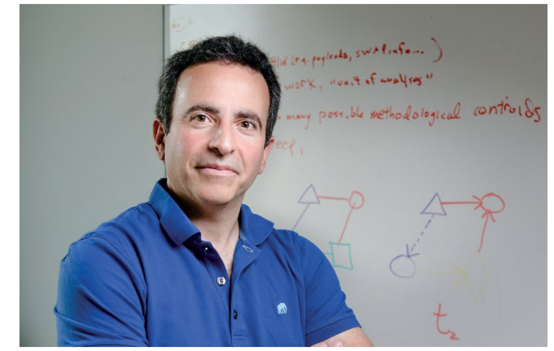
Pankaj Joshi

Danilo De Camargo Branco (PhD AAE '22)

Lecturers

Ronald Agyei (MSAAE '16, PhD AAE '21)

Thomas Cunningham (PhD AAE '22)



Professor **Dan DeLaurentis** was one of 28 people chosen for the American Institute of Aeronautics and Astronautics (AIAA) Class of 2023 Fellows. He was also appointed and accepted service into the Air Force Studies Board with the National Academies of Sciences, Engineering and Medicine; and was appointed vice president for research institutes and centers in the Discovery Park District at Purdue. Purdue's provost approved acknowledging DeLaurentis as the Bruce Reese Professor of Aeronautics and Astronautics.

The AIAA selected three AAE Boilermakers for its 2024 class of associate fellows: **Scott Meyer**, managing director of Maurice J. Zucrow Laboratories; **Michael Sangid**, professor; and **Haifeng Wang**, associate professor.

Sangid was also approved by the Purdue Board of Trustees to be named the Reilly Professor of Aeronautics and Astronautics.

For his contributions to Earth remote sensing using signals of opportunity, Professor **James Garrison** was elevated to fellow in the Institute of Electrical and Electronics Engineers (IEEE).

Professor **Karen Marais** was inducted into Purdue's Book of Great Teachers — a recognition of Purdue's finest educators. Twelve of the 467 names in the book are from AAE. The book was created in 1999 and is updated every five years. It is on permanent display in the Purdue Memorial Union.

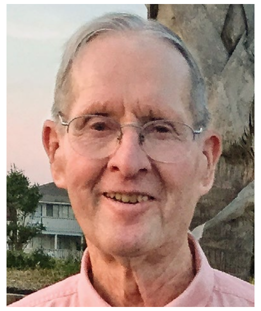
Professor **Jon Poggie** was selected in 2023 as a Purdue University Faculty Scholar. This award provides research funding annually for a five-year term. AAE professors James Garrison, Michael Sangid and Timothée Pourpoint are currently also University Faculty Scholars.

Joe Jewell, the John Bogdanoff Associate Professor of Aeronautics and Astronautics, accepted an invitation to the competitive Defense Science Study Group (DSSG), a DARPA-sponsored program. Members meet with top-level officials in government and intelligence agencies, the White House and Congress. They also visit military bases, defense laboratories and other research facilities across the country. This exclusive program has accepted just over 200 participants since it began in 1986.

Senior research associate **Waterloo Tsutsui** (PhD AAE '17) received the Engineering Education Excellence Award from the National Society of Professional Engineers. The award recognizes a demonstrated ability to link engineering education with professional practice.

The University of Michigan has given a Merit Award from the Department of Mechanical Engineering to **Tom Shih**, professor and former AAE department head. The award is part of the university's alumni recognition program.

IN MEMORIAM



Edward "Ed" G. Dorsey (1923-2022)

Born in Henderson, North Carolina, Edward "Ed" Dorsey spent much of his youth working on cars and listening to music. He had a lifelong love of jazz, and of tinkering.

He served in the U.S. Navy before attending Purdue, earning his bachelor's degree in 1946 with a Distinguished Student honor.

Dorsey began his aerospace career Experiment Inc., moving to Utah in 1958 for a job at Thiokol. He started there on the minuteman missile program, and then on the solid rocket boosters that would launch the space shuttle. He came out of retirement to lead the redesign team after the Challenger disaster.

Dorsey earned career accolades from NASA, the National Aeronautic Association and the State of Utah. He and his wife, Hilah, helped fund construction of Purdue's Neil Armstrong Hall of Engineering. Dorsey was named a Purdue Outstanding Aerospace Engineer in 2000.

William C. Kessler (1941-2023)

William Kessler was born in born in Bronx, New York. In 1956, his mother and stepfather moved to Kokomo, Indiana. After earning a bachelor's in 1964 and master's in 1965 from Purdue, Kessler began his engineering career at McDonnell Douglas and earned a chemical engineering doctorate from Washington University in 1974.

Kessler went to work in the Air Force in 1975, and rose to lead the Manufacturing Technology Directorate at Wright-Patterson Air Force Base. He became their foremost authority on advanced manufacturing and production technology at the Air Force. Starting at Lockheed Martin in 1997 as VP of enterprise productivity, he reduced manufacturing costs and implemented the Six Sigma program. He led design of a robotic coating system for the F22 that drastically cut costs.

He served as professor of industrial and systems engineering at Georgia Tech from 2007 until his retirement in 2015. Kessler was named a Purdue Outstanding Aerospace Engineer in 1999.

1940s

Cecil A. Baumgartner (BSAE '48)
Lawrence P. Fricke (BSAE '48)
John M. Vaught (BSAE '48)
Peter P. Bracke (BSAE '49)
Richard . Chute (BSAE '49)
Eldon L. Knuth (BSAE '49, MSAE '50)
Eldon E. Kordes (MSAE '49)
Sherrill R. McDonald (BSAE '49)
Warren V. Trammell (BSAE '49)

1950s

Stanley F. Lewiecki (BSAE '50)
Charles R. Lowes (BSAE '50)
William A. Browne (BSAE '51)
William Lc. Corcoran (BSAE '52)
Ralph A. McElheny (BSAE '52)
Howard P. Tangler (BSAE '52)
Donald J. Marcotte (BSAE '53)
Nancy A. Taylor (BSAE '53)
Harold L. Clark (BSAE '54)
Edward R. Freeland (BSAE '54)
Dale A. Smith (BSAE '54)
Deryl L. Denney (BSAE '56)
John M. Healy (BSAE '56)
John C. Woo (BSAE '56, MSAE '57)
Lucien C. Woodhouse (BSAE '56)
Robert E. Zimmerman (BSAE '56)
Donald H. Morton (BSAE '57)
John A. Ottlinger (BSAE '57)
Jon A. Study (BSAE '57)
David D. Dalenberg (BSAE '58)
David W. Simon (BSAE '58)
Walter C. Yeager (BSAE '58)
M. T. Zeller (BSAE '58)
Philip R. Atkinson (BSAE '59)
Wendell A. Fleener (BSAE '59)
Robert E. Geralde (BSAE '59)
Vernon L. Reed (BSAE '59)
John S. Stumph (BSAE '59)

1960s

Robert D. Lipscomb (BSAE '60)
Mickey R. Shanabarger (BSAE '61)
Donald K. Sykes (MSAE '61)
Jerry B. Sandifer (BSAE '62)
Eugene Scarl (BSAE '62)
John J. Bauer (BSAE '63)
Richard J. Mattes (BSAE '63)
Timothy J. Brand (BSAE '64)
Dennis P. Hilgenberg (BSAE '64)
Thomas V. Hinkle (BSAE '64)
James A. Hunsicker (BSAE '64)
Joel Sweet (BSAE '64, MSAE '65, PhDAE '69)
Joseph R. Garrahan (BSAE '65)
Michael J. Laughlin (BSAE '65)
Roy D. Gatherers (MSAE '66)
Daniel M. Sheets (BSAE '67)
Dennis J. Anderson (BSAE '68)
David M. Troyer (BSAE '69)

1970s

William B. Bigler (BSAE '70)
Robert C. Kaiser (BSAE '70)
Robert A. Walker (MSAE '70)
David P. Maynard (BSAE '71)
William G. Crorey (BSAE '72)
Darryl W. Hall (BSAE '72, MSAE '72)
Roger J. Wagner (MSAE '72, PhDAAE '74)
John P. Strickler (BSAAE '75)
Roy J. Mosolf (BSAAE '77)
James W. Livingston (BSAAE '78)

1980s

Anren Hu (MSAAE '81, PhDAAE '87)
Jerald M. Greenblatt (BSAAE '83)
Michael D. Seal (BSAAE '86, MSAAE '88)
Terence F. Fleming (BSAAE '87)

1990s

Angela C. Hasebe (BSAAE '97)

2000s

Nathan Lachendro (MSAAE '00)
Nickolas A. Bruno (BSAAE '04, MSAAE '07)

In Memoriam listings are based on those reported to us. Did we miss someone? Please let us know. Email Ashley Thompson: althompson@purdueforlife.org

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