

AEROGRAM

FALL 2020

PURDUE UNIVERSITY SCHOOL OF AERONAUTICS AND ASTRONAUTICS

CELEBRATING

75

YEARS

EST. 1945

PERSISTENT PURSUIT

AAE FORGES AHEAD AMID PANDEMIC

When students converged on campus to start Fall 2020, the vibe — and the look — was considerably different than one year ago. Banners and signage draped main buildings, calling for the community to “Protect Purdue” amid the COVID-19 pandemic. Across campus, including Neil Armstrong Hall of Engineering — the home of the School of Aeronautics and Astronautics — decals placed on classroom seats marked proper social distancing and hand sanitizer stations were installed in each entryway.

Despite the coronavirus, a record number of students enrolled in AAE this fall, and many of those students attended in-person classes that adhered to social distancing and mandatory face coverings, while also mixing in online courses. AAE faculty worked tirelessly

to prepare for the hybrid learning approach, earning praise from William Crossley, the J. William Uhrig and Anastasia Vournas Head of Aeronautics and Astronautics. Crossley, too, championed the resilience and persistence of the AAE student body, its willingness to adjust to change and excel despite the circumstances.

Regardless of the challenges that lie ahead, Crossley knows AAE will thrive.

“Through this, we’re still pursuing the highest levels of innovation and discovery, and we’re trying to help solve industry’s toughest challenges through our research work,” Crossley said. “We’re going to keep our top priority on making sure that the students have the maximum experience they can, given the current situation.”

PHOTO: Reminders of COVID-19’s impact on Purdue University were visible across campus in the fall. (Rebecca McElhoe/Purdue University)



AEROGram

is an annual publication for the alumni and friends of the Purdue University School of Aeronautics and Astronautics. Unless otherwise noted, articles in *Aerogram* may be reprinted without permission. Appropriate credit is appreciated.

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School of Aeronautics
and Astronautics

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ON THE COVER: Neil Armstrong Hall of Engineering is the flagship building of the College of Engineering. Its soaring, cantilevered roofline provides a dramatic, welcoming northern gateway to Purdue's campus. (Charles Jischke)

CELEBRATING

75 YEARS

SCHOOL OF AERONAUTICS AND ASTRONAUTICS

For 75 years, the School of Aeronautics and Astronautics has been leading innovation in aerospace engineering. Stay up to date on anniversary events, stories and social media throughout the yearlong celebration: <https://bit.ly/AAE75th>



WILLIAM CROSSLEY

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

I am writing this letter as classes have begun for the Fall 2020 semester while the COVID-19 pandemic continues. Aeronautics and Astronautics is doing our part to support the Protect Purdue Plan; we adjusted courses using de-densified classrooms, converted some to hybrid models that mix remote and in-person options and made some fully online. Lab courses are spaced through the day, using additional personal protective equipment (PPE) when social distancing is not possible. Nearly all research conducted in on-campus facilities has resumed, with procedures in place for maintaining social distance in the laboratory spaces and researchers wearing PPE when that distancing is not possible. When on campus, we are all wearing masks inside buildings; outside, we wear masks when we cannot ensure appropriate distancing. We operate many functions remotely to reduce the number of staff on campus. Research that is largely analytical or computational has continued in a remote format.

So far, it is working. There are no guarantees, as President Mitch Daniels states. As you read this, we will be readying for the Spring 2021 semester. Things are a bit different, but we are working together to pursue all of the things that make us the School of Aeronautics and Astronautics.

We have had some changes in the faculty. Associate Professor David Spencer left Purdue to become the mission manager for the Mars Sample Return Campaign at NASA's Jet Propulsion Laboratory. This is a big loss for the School and a great opportunity for Dave. Associate Professor Ran Dai joined the autonomy and control area. She comes to Purdue after faculty positions at Iowa

State and Ohio State. Assistant Professor Dianyun Zhang joined our structures and materials area. She comes to Purdue after a faculty position at the University of Connecticut. Our new research faculty member is Assistant Professor Brandon Chynoweth. Previously, he was a research scholar/research scientist in Aeronautics and Astronautics in our aerodynamics area.

The School started the Fall 2020 semester with record student enrollment — 959 undergraduate and 587 graduate students. We are also celebrating our 75th anniversary during the 2020-21 academic year. On July 1, 1945, the School of Aeronautics became an independent academic unit at Purdue. The changes over the last 75 years have been astounding.

This issue of *Aerogram* also has a few changes. As *Aerogram* grew from a short newsletter into a magazine, the School's internet and social media presence also has grown. We now have a robust set of news items and frequent updates on our website along with links to our social media accounts. So this issue of *Aerogram* emphasizes research activities in stories aligned with four themes. We have moved the primary delivery of *Aerogram* to online; this allows for more dynamic content and in-story links, while saving some cost during the COVID-19 pandemic. There are some updates here as a “year-in-review,” while the majority of our news items are available online.

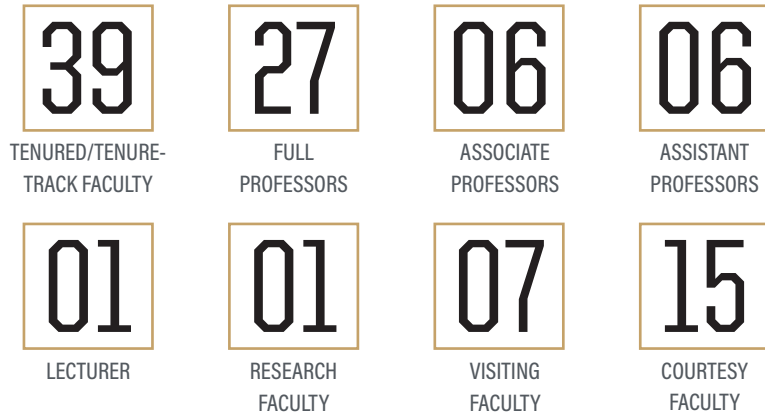
I hope that you and all of those close to you are doing what you need to do to stay safe and healthy. I look forward to when we will be able to welcome you back to campus. Until then, “Boiler up, mask up, and Hail Purdue!”

AERONAUTICS AND ASTRONAUTICS BY THE NUMBERS

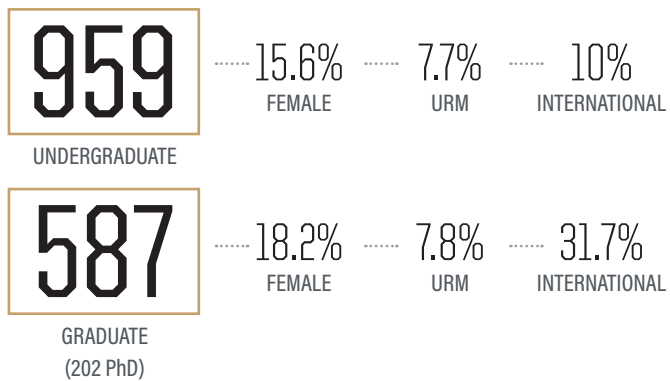
RANKED **5**TH
 BEST UNDERGRADUATE
 AEROSPACE/
 AERONAUTICAL/
 ASTRONAUTICAL
 ENGINEERING
*U.S. News and World Report
 (2021)*

RANKED **6**TH
 BEST GRADUATE
 AEROSPACE/
 AERONAUTICAL/
 ASTRONAUTICAL
 ENGINEERING
*U.S. News and World Report
 (2021)*

THE FACULTY (FALL 2020)

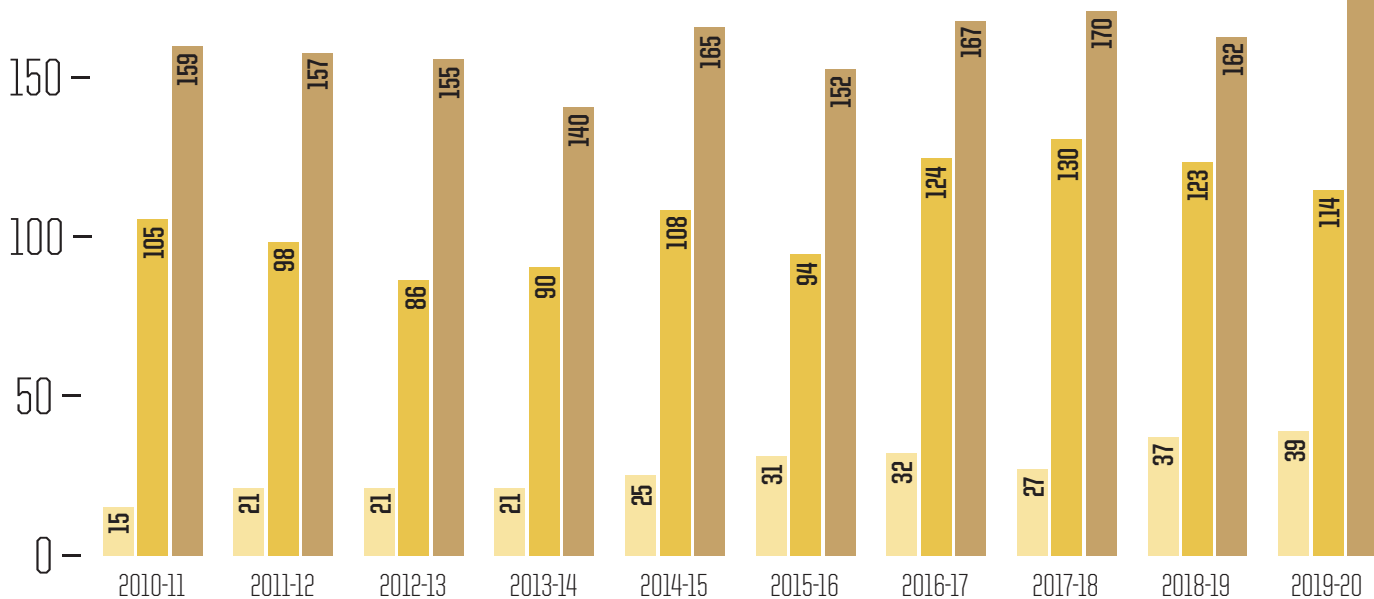


THE STUDENTS (2020 FALL ENROLLMENT)



250 — **LAST DECADE:
GRADUATES**

200 — **- PhD - MS - BS**



ADVANCING, ENABLING FUTURE OF AEROSPACE

AAE'S WORK EXTENDS BEYOND AREA COMMITTEES

WILLIAM CROSSLEY

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

We often categorize the research and teaching work we do in Aeronautics and Astronautics into so-called “area committees” that help us organize the School. However, our work at Purdue really is helping to advance and enable the future of aerospace. To help others understand our impact and to help us in the School see how our work really unites us, we have introduced four themes:



01

SAFE, EFFICIENT AND SUSTAINABLE AIR TRANSPORTATION

While the COVID-19 pandemic has driven passenger air travel demand to very low levels, most industry analysts see a rapid return once the coronavirus can be properly managed. Air transportation of people and goods helps make the world smaller; we can meet others for business or education or leisure. Flying is one of the safest means of transport and is often the fastest. As the demand for air travel returns, aerospace engineers need to ensure that air travel remains the safest means of transport. To make it accessible, we need to ensure efficiency in terms of both the aircraft and the airspace. While aviation contributes a relatively small amount of carbon and greenhouse gas emissions, the contribution is visible. Noise and air quality near airports are constant concerns. Aerospace engineers need to do our part to ensure we can provide the benefits of air transportation without a deleterious impact on the environment.

ACCESS TO AND EXPLORATION OF SPACE



From communications and GPS satellites, to science on board the International Space Station, to humans returning to the moon and venturing to Mars, to spacecraft exploring other planets and objects in the solar system, aerospace engineers have enabled many breakthroughs in understanding our place in the universe and have made possible many things we take for granted — “in a quarter mile, turn right onto Stadium Avenue,” for instance. As always, getting off of the Earth has always been difficult and expensive. Improved propellants and propulsion concepts will help. Navigating through space requires trajectory designs to get a spacecraft where it needs to be when it needs to be there. Once in space, particularly in Earth orbit, space situational awareness can allow spacecraft operators to be aware of potential hazards of debris.

MAINTAINING DEFENSE AND SECURITY



Aerospace plays a major role in providing defense and security to the United States and our allied nations. Air power has been a decisive advantage in conflicts and having a strong deterrent capability via missiles and bomber aircraft remains part of the nation's defense strategy. In addition, assets in space to provide awareness and communication are crucial to our armed forces. Aerospace also plays a role in developing approaches to protect citizens and soldiers from potential attacks.

USING AEROSPACE TO FACILITATE NEW OPPORTUNITIES



The ubiquity of GPS navigation in our automobiles or via our phones is an obvious example of an opportunity enabled by aerospace. Low-Earth orbit constellations that provide near global coverage for internet access are now taking shape. Remote sensing and observation from spacecraft or aircraft are changing agriculture, providing disaster relief and monitoring our changing climate. Urban air mobility ideas will use aircraft to reduce commute times in congested metropolitan areas, with the promise of increased productivity. To-the-door delivery via UAS is already a desired opportunity, and aerospace engineers contribute to making the air vehicle safe, reliable, robust and autonomous.

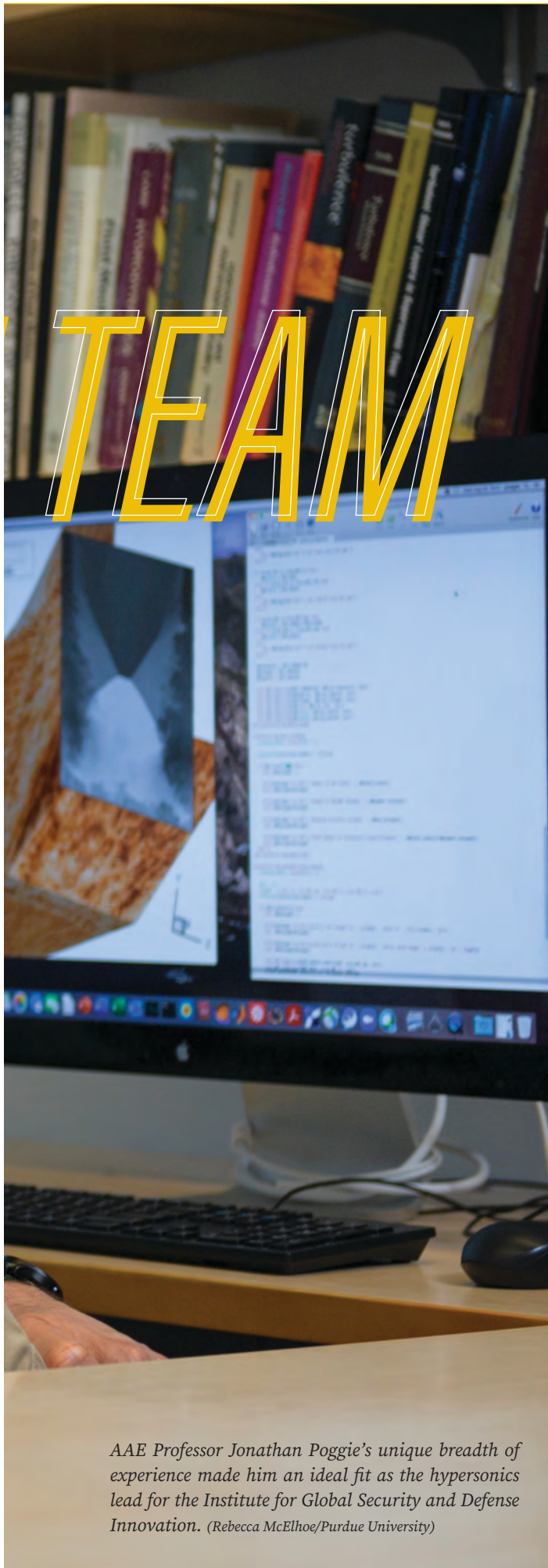
(Boeing)



THE DREAM

FUELED BY MULTIDISCIPLINARY
APPROACH, PURDUE POISED TO
DEVELOP NEXT GENERATION OF
HYPERSONIC VEHICLES

TEAM



AAE Professor Jonathan Poggie's unique breadth of experience made him an ideal fit as the hypersonics lead for the Institute for Global Security and Defense Innovation. (Rebecca McElhoe/Purdue University)



Assoc. Professor Sally Bane



Professor Gregory Blaisdell



Research Asst. Professor Brandon Chynoweth



Professor Daniel DeLaurentis



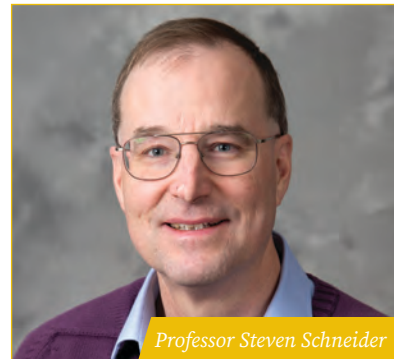
Professor Stephen Heister



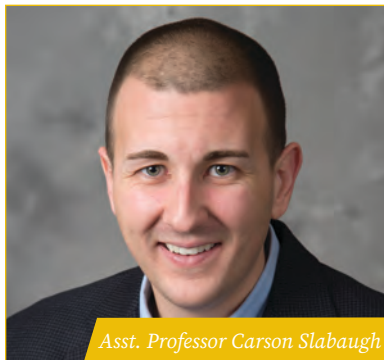
Asst. Professor Joseph Jewell



Professor Timothée Pourpoint



Professor Steven Schneider



Asst. Professor Carson Slabaugh



Professor Vikas Tomar

Jonathan Poggie used to be an experimentalist.

He signed on with the Air Force Research Laboratory (AFRL) in his last couple of years of graduate school at Princeton University, and he quickly got plugged in on wind tunnel experiments in a supersonic wind tunnel. After receiving his PhD, Poggie went to work at Wright-Patterson Air Force Base and moved to hypersonic wind tunnel experiments and boundary layer transition, focusing on the prediction and control of flow at extremely high speeds.

When funding for experimental work dried up after the Cold War, Poggie switched to a team that did computations, and he worked on computations of hypersonic flows and plasmas. After a few years, he was promoted to team lead, providing strategic research and development advice to the organization, and helping to prioritize and steer multiple research projects.

By 2015, when Poggie was recruited by AAE Professor Sergey Macheret to join Purdue University's Preeminent Team in cold plasmas, Poggie was an internationally recognized authority in the computational, theoretical and experimental aspects of fluid and plasma dynamics.

His unique breadth of experience made him an ideal fit as the hypersonics lead for the Institute for Global Security and Defense Innovation, Purdue's defense research center. Daniel DeLaurentis, the director of i-GSDI, tagged Poggie specifically for the role, valuing Poggie's versatility, persistence and expertise.

"My background is relatively unusual in academia. Generally, people specialize," Poggie said. "I've done wind tunnel experiments. I've done computations. I've done low-speed flow and high-speed flow and plasmas. I've also done program management for the government, so I've run teams of researchers where I was not involved in the technical work.

"I can provide some perspective on what the government might want and some insight into what's particularly valuable to the government, what they have trouble with, what they need."

One of Poggie's first responsibilities in his new role with i-GSDI was identifying researchers at Purdue with an interest in hypersonics and assembling a multidisciplinary team. By August 2020, he had 38 names on a spreadsheet.

The group's expertise includes navigation, aerodynamics, aerothermal effects,

propulsion, autonomy, system engineering, high-temperature materials and manufacturing. The aim is to assist government and industry in laying the groundwork for developing the next generation of high-speed vehicles capable of flying at Mach 6 — more than 4,000 mph — and beyond.

"It's like the dream team of hypersonics," Poggie said. "There's really a lot of interesting potential that could come out of this."

This is a crucial moment in the field of hypersonic flow research. Intense international competition has driven the Department of Defense to greatly increase support for the area, and research at Purdue can directly support development of the technology and, just as importantly, develop the next generation workforce for industry and government. Purdue certainly has been moving forward in both.

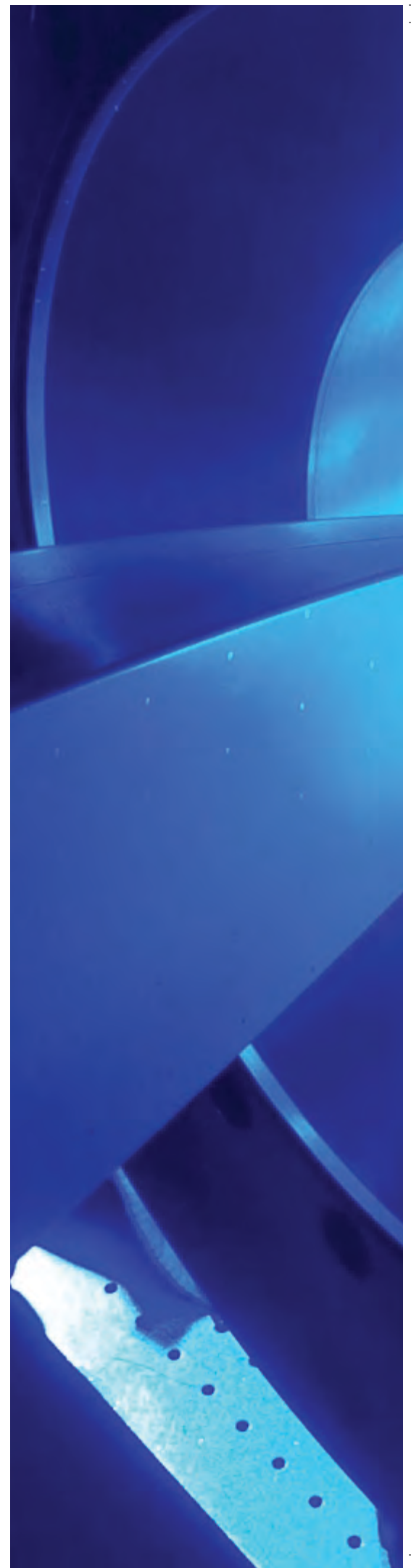
FORGING NEW PARTNERSHIPS

In May 2019, Purdue partnered with the University of Dayton Research Institute and the University of Tennessee Space Institute to support AFRL flight testing on the X-60A vehicle — an airdropped liquid rocket specifically designed for hypersonic flight research. Purdue is supporting AFRL's testing by doing computations, led by Poggie and AAE Professor Gregory Blaisdell, and experiments in the Boeing/AFOSR Mach 6 quiet tunnel on components of the flight test vehicle with AAE Professor Steven Schneider and Assistant Professor Joseph Jewell and Research Assistant Professor Brandon Chynoweth.

In June 2020, Purdue signed an agreement with the Johns Hopkins University Applied Physics Laboratory to collaborate on hypersonic research and related technologies. The research will make heavy use of the Mach 6 quiet tunnel.

In Summer 2020, the multidisciplinary team Poggie assembled helped Purdue secure a \$5.8-million contract with AFRL, focusing on fundamental tools that could be used for a variety of systems. That work will include 15 faculty and researchers, 11 in AAE, three in other schools in the College of Engineering and one at Notre Dame.

The research includes five tasks, four of which are led by AAE professors. Inlet and external flow performance in quiet flow wind tunnels is directed by Jewell. Reducing uncertainty in turbulent flow



modeling will be led by Sally Bane, an associate professor in AAE. DeLaurentis, a professor in AAE, will direct model-based systems analysis for hypersonic vehicle design, and Carson Slabaugh, an AAE assistant professor, will lead scramjet combustion experiments.

Schneider, Poggie and Chynoweth will aid in quiet hypersonic wind tunnel experiments. Blaisdell, Poggie and mechanical engineering's Terrence Meyer and Guillermo Paniagua will be involved in turbulence modeling. AAE Professor Vikas Tomar will aid in systems engineering work. Raisbeck Engineering Distinguished Professor for Engineering and Technology Integration Stephen Heister and Timothee Pourpoint, an AAE professor, will join Slabaugh in scramjet performance research.

"One of the reasons a multidisciplinary team was important is it's very hard to break down the challenges of designing the hypersonic plane into separate fields because everything is integrated," Poggie said. "The major challenge in designing a hypersonic vehicle is dealing with high heat transfer. Flying through the air very fast involves a lot of heating due to compression and friction, and you have to deal with that. So that influences how you design the aerodynamics, it influences how you design the structure and what materials you select, and how you design the engine, so all of these things that were formerly independent fields now become really tied together."

A PERSISTENT PURSUIT

Purdue has a strong reputation in the hypersonics field, in part because when many others in the country stopped supporting the field, Purdue did not. Instead, it practiced "unusual persistence," DeLaurentis said.

Schneider's persistent pursuit in developing the Mach 6 quiet Tunnel, which ran its first successful tests in quiet flow in 2006, planted the seed for Purdue's sought-out partnership. The facility is like few in the world with its ability to test in "quiet" conditions, important because that simulates hypersonic flight. But it didn't stop with Schneider, a world expert in boundary layer transition. Jewell, an assistant professor hired in 2019, now leads the Mach 6 tunnel, and Chynoweth was hired as a research assistant professor in June 2020 as co-principal investigator with Schneider to develop a

new Mach 8 quiet tunnel.

When Purdue sought to fill out a team around Schneider's success with the Mach 6 quiet tunnel, they tabbed Poggie. Mechanical engineering hired Carlo Scalo. Researchers in high-temperature materials were willing to do multidisciplinary work, DeLaurentis said. Researchers at the Maurice J. Zucrow Laboratories have been developing innovative solutions to hypersonic propulsion.

"One could argue Purdue really has been only one of two or three universities in the whole nation that actually kept investing more in hypersonics and therefore was drawing more of the support that the government started to loosen up," DeLaurentis said. "Then those people were quite collaborative, and they had partners at other universities, so Purdue, I think, became known as a natural leader of partnerships.

"Over the last two, three years especially, Purdue has really tried to step forward as a national leader to bring together universities for multidisciplinary research in hypersonics because the progress we need to make, the timeline is so quick. Having isolated projects, almost via a coin flip, you lose great ideas just because isolated projects are hard to integrate. We've been trying to lead the charge to have universities work closer together and then work on multidisciplinary projects that help minimize the loss of great ideas."

All of it adds up to confidence: Purdue will continue to be a leader in hypersonics and a key partner for years to come, Poggie said.

"Experimental facilities take a long time to build and they require team knowledge to use effectively, and we've got that and that's not going away. If the DoD continues to need experiments, we'll be there to do that," Poggie said. "We also have deep group knowledge in the modeling of flows, how to effectively run computations on very large computers, which involves the same kinds of frustrations of running complicated experiments. If you push the limits of computers, you discover that you need to learn a whole bunch of computer science you didn't want to know. We've developed that through painful work. So we have this reservoir of knowledge and equipment that can serve this area. So as long as the government and private industry are looking at hypersonics, we can be there to help."

The Johns Hopkins Applied Physics Laboratory and Purdue University signed an agreement that will allow both institutions to harness one another's capabilities and expertise in the field of hypersonics. The agreement centers on hypersonic research and related technologies with APL staff members having enhanced access to Purdue's wind tunnel facilities, including the Boeing/AFOSR Mach-6 quiet wind tunnel (pictured).

(AFOSR/Johns Hopkins APL)



*COMBATING
INTELLIGENT
ADVERSARIES*

INNOVATIVE
TECHNIQUES
DEVELOPED TO
ASSURE AUTONOMY
OF MULTI-AGENT
PLATFORMS
IN CERTAIN
ENVIRONMENTS



Shaoshuai Mou, an assistant professor in AAE, and students in his Autonomous & Intelligent Multi-Agent Systems Lab are developing innovative techniques to assure autonomy of multi-agent platforms in unknown, dynamically changing and adversarial environments. (Rebecca McElhoe/Purdue University)

Autonomous platforms have evolved from individual systems — a single autonomous aerial vehicle, for instance — to networks of autonomous agents, like a mixture of aerial and ground vehicles along with mobile sensors, that are able to sense the environment, engage in high-level decision making and execute their actions without direct human interaction.

By working as a cohesive whole, multi-agent platforms (MAP) usually offer a higher degree of autonomy for complicated missions, such as search and rescue and assisting soldiers on battlefields. The absence of a central controller makes MAP inherently robust against individual agent and link failures as long as the underlying network is connected. Dependence of the whole MAP on local coordination among neighbors also makes MAP vulnerable to intelligent cyberattacks.

The operational environment of autonomous MAP in practical applications is becoming more contested with potentially intelligent adversaries. If a sophisticated adversary wanted to disrupt operations of the MAP, it could employ advanced techniques — much like a computer virus — that would be rapidly infectious to all of the agents on the network. Attacks with these techniques could be launched against many different points in the MAP network because there are so many agents in the network.

In most MAPs, each agent is a low-cost system, can only access information that is local to that agent and has no centralized entity that monitors activities of the entire MAP. This can make assuring the performance and intended action of the MAP particularly challenging in the face of intelligent adversaries seeking to disrupt the MAP.

Shaoshuai Mou, an assistant professor in AAE, will combine recent advancements in artificial intelligence and machine learning with classical theories in networks, control and optimization to develop innovative techniques that assure autonomy of multi-agent platforms in unknown, dynamically changing and adversarial environments.

“We could utilize machine learning to make ourselves stronger, but the cyber attacker could also use artificial intelligence to make them stronger. The situation becomes worse when such intelligent adversaries could fully control an autonomous agent and crash the whole MAP by doing arbitrarily bad things while pretending to be a good agent,” Mou said. “Our job is to design resilient controllers to collaborate and work with each other. So even if some agents become bad, the whole MAP could still continue functioning.”

Because the whole multi-agent platform relies on coordination and sharing information, consensus is the key for the multi-agent system to work as a cohesive whole.

“Once the consensus goal is violated by cyberattacks, it would be hard for MAP, such as a drone swarm, to collaborate,” Mou said.

AI and machine learning are able to automatically analyze large amounts of data, provide timely decisions and improve with experience. Mou’s research, funded by the Northrop Grumman Cybersecurity Research Consortium, will use techniques that will be automated for real-time response of detection of and defense from massive and rapid attacks, effective for mitigation of the degradation in performance as a result of intelligent threats, adaptive to time-varying attacks in various mission scenarios and dynamically changing environments, and distributed to provide protections for large-scale multi-agent platforms especially when local coordination is available. The project is not purely computational: Students also will test the algorithms with drones in the Autonomous & Intelligent Multi-Agent Systems Lab.

“Our goal is to combine the AI learning with control of multi-agent networks to assure that we can still achieve some satisfaction performance even in the presence of some intelligent adversaries,” Mou said.

PUSHING

W
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T
T

(Johns Hopkins University Applied Physics Laboratory)

BOUNDARY

UNIQUE BOLT EXPERIMENT EYES 2021 LAUNCH

MAINTAINING DEFENSE AND SECURITY

THE NAME MAY BE SIMPLISTIC, BUT THE RESEARCH CERTAINLY IS NOT.

When the Boundary Layer Transition (BOLT) Experiment and its unique, complex shape launches on a sounding rocket in 2021 — the culmination of computational analyses and wind tunnel tests conducted over three years — it'll measure boundary layer transition and obtain validation data in hypersonic flight.

Data that never has been collected. BOLT was designed to push the limits of research flight tests, under a grant from the Air Force Office of Scientific Research, using a more complex geometry than past flight experiments specifically to introduce different instabilities within the boundary layer that can cause transition. BOLT's unique shape features a low-curvature concave surface with highly swept leading edges.

Accurately predicting when the air over the surface of a hypersonic vehicle ("boundary layer") transitions from being smooth to turbulent on a vehicle flying faster than the speed of sound is incredibly difficult even under the best of circumstances, when a conical-type shape is tested, at varying speeds and altitudes. But accurately predicting the state of the boundary layer is critical research in the design and development of hypersonic vehicles and missiles, as a smooth boundary layer helps prevent overheating and can reduce aerodynamic drag.

"Rather than fly a geometry that was simple and really was expected to incite a certain type of instability that would lead to boundary layer transition, BOLT is a much more complex geometry and we actually didn't know before we started what would cause boundary layer transition on it," said Johns Hopkins Applied Physics Laboratory's Brad Wheaton, the principal investigator on BOLT. "We're doing a lot of research to learn that, so it's driving our analysis and testing capabilities toward more complex geometries and more complex physics."

APL was selected as the organization to lead a team of universities, private companies and government organizations on the unique flight test. The AFOSR's announcement included a Purdue University partnership, but that would have been a natural fit for Wheaton and APL anyway. For a variety of reasons.

Purdue has extensive expertise in boundary layer transition and unique facilities to aid in the research, and Wheaton and Dennis Berridge, BOLT's co-investigator and ground test lead at APL, are AAE alumni. Greg McKiernan started working on BOLT while pursuing his PhD in AAE and now is an engineer for APL after joining it full time in June 2020. Longtime AAE Professor Steven Schneider, who developed Purdue's Boeing/AFOSR Mach 6 quiet tunnel, was the advisor for all three.

"It's been spectacular. The collaboration, the idea exchange has been really fulfilling," Wheaton said of the partnership with Purdue. "APL designed and built the wind tunnel model, and Purdue was able to offer their expertise and guidance into the design of the model and the selection of instrumentation, and the support from Professor Schneider's group was instrumental because we could leverage the expertise of the students."

Purdue was in the picture early on in the project, consulting with the Air Force on the geometry. After APL was awarded the lead, Schneider was looking for an AAE student to be a major point of contact to help them complete the testing. McKiernan already was working on his PhD, but he stepped up anyway.

"It was really the fact that it was a very unique experiment. There aren't too many sounding rocket flight tests that happen, that whoever was going to lead the testing would have a big hand in driving a bunch of the research behind the sounding rocket flight," McKiernan said. "That was just an exciting, unique experience that I volunteered for."

While at Purdue, McKiernan (MSAAE '16, PhD '20) ran three full-week wind tunnel entries and an additional weekend or two "when I snuck in as well" to get data to answer various questions that came up throughout the design of the flight experiment.



Brad Wheaton, an AAE alumnus and principal investigator on BOLT, during vibration testing of the flight hardware.

(John Hopkins University APL)

"PURDUE WAS ABLE TO OFFER THEIR EXPERTISE AND GUIDANCE INTO THE DESIGN OF THE MODEL AND THE SELECTION OF INSTRUMENTATION, AND THE SUPPORT FROM PROFESSOR SCHNEIDER'S GROUP WAS INSTRUMENTAL BECAUSE WE COULD LEVERAGE THE EXPERTISE OF THE STUDENTS."

- BRAD WHEATON



AAE alumni and APL staff members Dennis Berridge and Wheaton (first two on left) welcomed APL then-interns in 2018 to work on BOLT, including from left to right, Heather Kostak (Texas A&M), Greg McKiernan (Purdue University) and John Thome (University of Minnesota). McKiernan joined APL full time in June 2020.

(John Hopkins University APL)

The grant started in September 2017, and the team was under an aggressive schedule that required significant wind tunnel testing at a variety of different facilities in the first year, as well as a large amount of analysis. Initial tests at Purdue were more exploratory, McKiernan said. There was a general idea what to expect from computations from other facilities, but because the Mach 6 quiet tunnel is so novel — its ability to conduct measurements in “quiet” conditions, which more closely simulate flight, is unique in the world — testing there provided a “new look at what was going on with the model,” he said. As the testing progressed, a better idea of the BOLT flow physics emerged and that drove instrumentation placement and types of runs and conditions.

Schneider, now-research assistant professor Brandon Chynoweth, McKiernan and current AAE graduate student Chris Yam all ran experiments for the project in the quiet tunnel. Wheaton (MSAAE '09, PhD AAE '12) and Berridge (MSAAE '10, PhD AAE '15) also visited to Purdue to oversee tests.

“Essentially the features that we’re able to see under quiet flow on BOLT, we really can’t see them in any other tunnel just because the noise of the tunnel basically dominates the flow field,” Wheaton said. “So we have a really unique perspective of into what the laminar flow might potentially look like in flight. That’s basically what has been so instrumental in testing at Purdue.”

During one of project’s design reviews, there was some concern about having small steps on the hardware between the interfaces of the different materials. Within six weeks after that design review, APL and Purdue were able to design and execute a wind tunnel test that helped gather data about

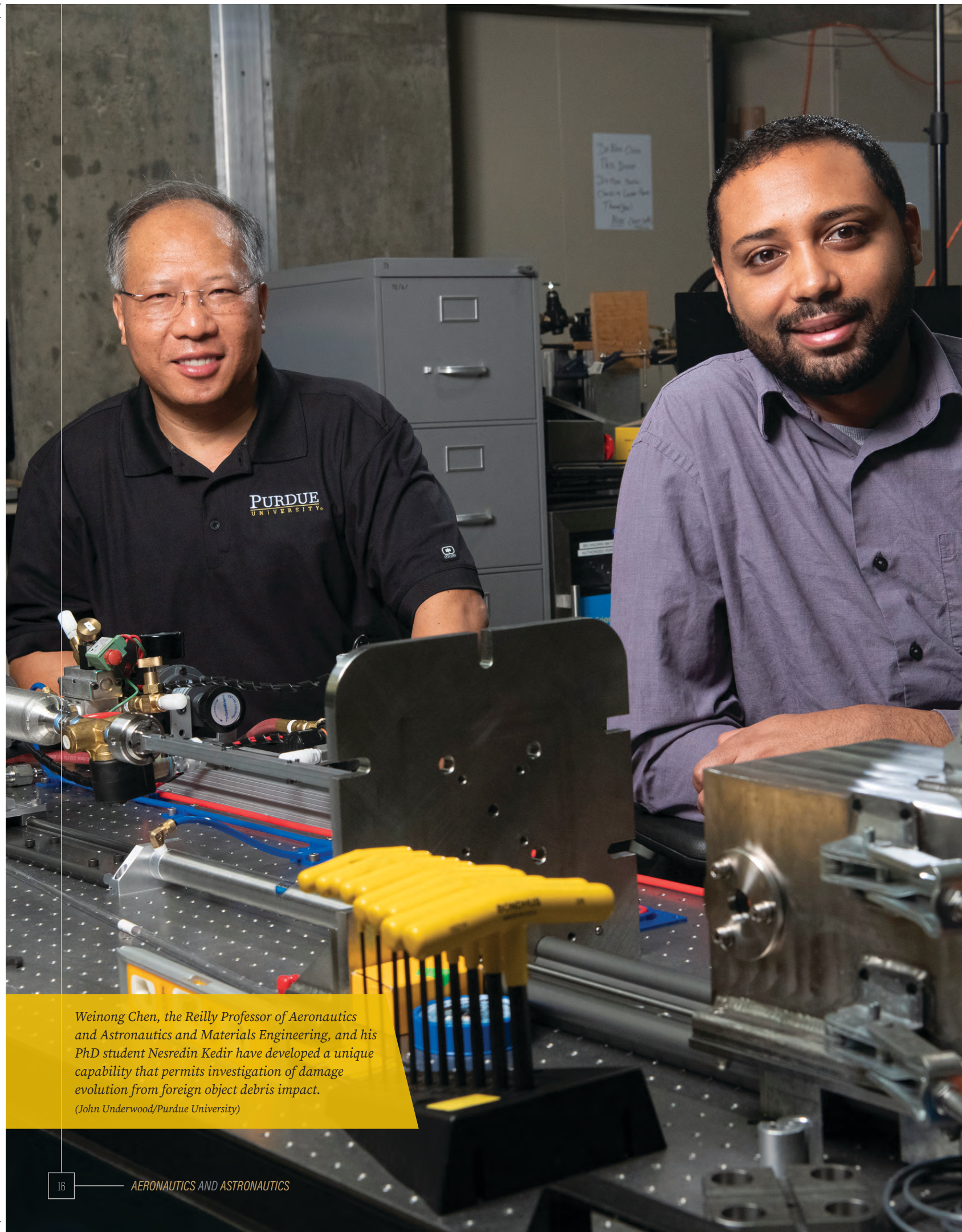
what those very small steps might do if they were present in flight and gain confidence that the expected steps would not influence the boundary layer transition experiment. APL built hardware to modify the model by putting different nose tips on it and sent it to Purdue. Chynoweth ran the test.

Yam, who learned about the project while discussing potential master’s topics with Schneider, assisted in two rounds of measurements on the flight experiment to confirm the step heights of each joint, consisting of day trips to Wright-Patterson Air Force Base to make a handful of measurements and then analyzing those at Purdue. Yam’s research is further exploring the effect of the various small steps on the BOLT geometry, as he’ll spend 2020-21 gathering and analyzing data on the wind tunnel model (one-third scale of BOLT) in the facility.

“If all goes well, the data collected should serve as a good comparison point to interpret the flight data,” said Yam, whose advisors on the project are Schneider and Joseph Jewell, an assistant professor in AAE. “It’s possible that I’ll see this project in my future career. Perhaps I’ll even work on the future flight program, BOLT-2.”

In a two-year period, BOLT went from a concept for the front of the rocket to a complete scientific research campaign to designing the flight hardware, the instrumentation and building it. Flight hardware was completed at APL and delivered to the Air Force in November 2019. COVID-19 pushed back the initially projected launch window from May 2020 to April or May 2021. The flight test will be conducted in Northern Sweden.

“We’re trying to be patient. We’ll get there, eventually,” Wheaton said.



Weinong Chen, the Reilly Professor of Aeronautics and Astronautics and Materials Engineering, and his PhD student Nesredin Kadir have developed a unique capability that permits investigation of damage evolution from foreign object debris impact.
(John Underwood/Purdue University)



TARGETING EFFICIENT, ECO-FRIENDLY GAS TURBINE ENGINES

IMPACT SCIENCE
LABORATORY
WORKS TO
RESOLVE FOREIGN
OBJECT DEBRIS
IMPACT

Emerging designs for next-generation gas turbine engines aim to enable air travel and energy production with lower fuel consumptions and reduced greenhouse gas emissions. One of the promising designs seeks to operate the engine at higher temperatures and tap into additional energy that is given off from the fuel burn process. The approach requires materials that are able to withstand the ensuing harsh engine environment with equivalent or higher reliability during service.

Advanced ceramics and ceramic matrix composites (CMCs) are candidate materials for replacement of traditional Nickel-based super alloy components in the hot sections of aero engines. These materials offer a reduction in weight and a capability to increase the operating temperature. Those enhancements lead to an improvement in efficiency.

A key requirement for application of these materials in-service is the application of a protective ceramic layer against high-temperature oxidation, referred to as an environmental barrier coating. Both the substrate and coating layer are inherently brittle and susceptible to fracture failures. A major source of fracture failure in the engine operating environment is impact by foreign object debris (FOD).

The Impact Science Laboratory, led by Weinong Chen, the Reilly Professor of Aeronautics and Astronautics and Materials Engineering, is part of the effort to resolve this challenge by conducting fundamental research that aims to uncover the underlying damage processes.

In collaboration with the high-speed X-ray imaging group at the Advanced Photon Source (APS 32-IDB, Argonne National Lab), Chen and his PhD student Nesredin Kedir have developed a unique capability that permits investigation of damage evolution for the FOD impact problem. The work combines a high energy and extremely bright X-ray beam available at APS 32 ID-B with a small particle gas gun apparatus. The experimental setup allows users to observe in real time the start and growth of damage inside samples during a simulated FOD impact.

Ceramic samples with and without coating have been investigated at relevant impact velocities. Limitations in damage prevention by the coating also have been identified from these visualization studies.

Experiments have been conducted using different foreign object simulants (materials). Due to changes in the thickness of the turbine blade near the edges, thinner samples also were examined under similar impact conditions. Portions of the damage histories generated as part of this effort were provided to external participants to duplicate with computer models.

Further dissemination of the knowledge gained from these experimental works will promote additional simulation efforts and lead to a state where new materials and part geometries are able to be examined digitally with confidence. Ultimately, such a combined effort between experiment and simulation will resolve the challenge of FOD impact and lead to extensive substitution of current metallic components with CMCs for more efficient and eco-friendly gas turbine engines.

THE FUTURE OF *EDGE COMPUTING*

HIGH CAPACITY BATTERIES KEY TO EVOLVING AUTONOMOUS SYSTEMS



“THE PROBLEM IS THAT CURRENT BATTERY CHARGE CAPACITY IS VERY LOW, IN ORDER TO MAINTAIN THEIR STABILITY AND MAKE THEM SAFER. BUT AUTONOMOUS DEVICES REQUIRE HIGH CAPACITY BATTERIES TO OPERATE.”

- VIKAS TOMAR

Cloud computing supports a vast array of information and systems every day. Whether it's Google, social media or file storage, billions of people rely on the internet to stay connected. When that connection is interrupted, it causes inconvenience for the average user. However, if autonomous systems were to rely solely on cloud computing, maintaining a connection could mean the difference between safe operation and disaster. Imagine a self-driving car that required a stable cellular connection to avoid collision.

For federal agencies, cloud computing presents additional security concerns surrounding the possibility of data being intercepted in transmission. Heavy encryption requires high computational power, which in turn requires a great deal of energy to operate. Communicating with the cloud can also cause delays in response time, as information is passed from the site to the computational data center and back again. Mission-critical operations rely on edge computing to process time-sensitive data. The trade-off is that high volume edge computing — computation that occurs at the local device — requires strong power supplies, often in the form of thousands of batteries.

“Battery technology in the United States is way behind in terms of manufacturing,” said Vikas Tomar, professor of aeronautics and astronautics. “The problem is that current battery charge capacity is very low, in order to maintain their stability and make them safer. But autonomous devices require high capacity batteries to operate.”

The optimal combination for autonomous devices is a hybrid of cloud and edge computing. At present, high voltage batteries needed for efficient edge computing are costly and unstable. In collaboration with AAE Associate Professor Dengfeng Sun, Tomar uses machine learning to

(Rebecca McElilho/Purdue University)

measure the efficacy and stability of high capacity batteries using sensors the team has developed.

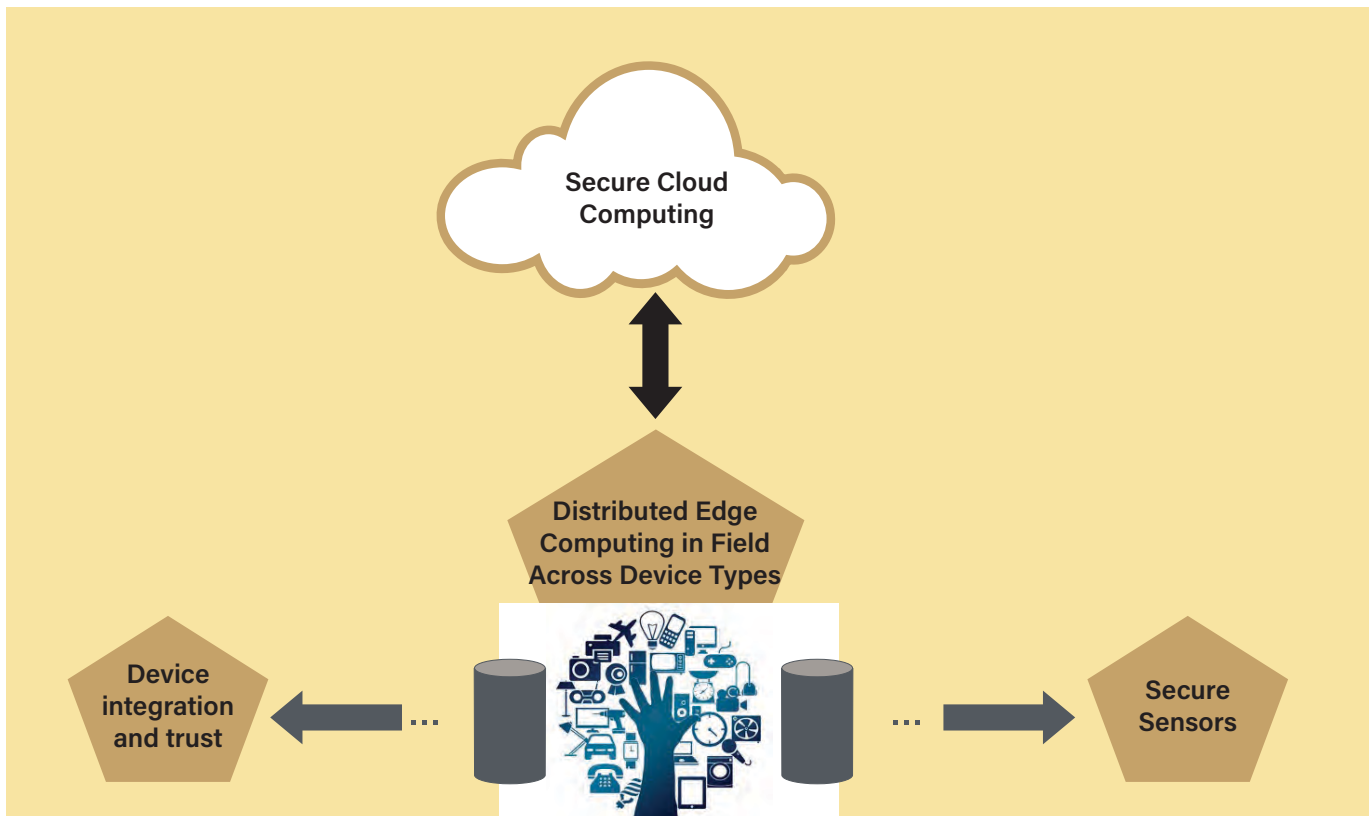
The team incorporates management systems to collect data on the performance of high capacity batteries to determine how they fail and how that failure can be managed. The systems will also review the manufacturer's history and ideal operational conditions of the device to make a determination of the safety of the system and how much it should be charging.

"The balance of edge and cloud computing is very important and varies among systems," Tomar said. "Do you need quick decisions? How many systems are there? Are you dealing with thousands of devices vs. one device? The key thing is to improve energy device security based

on the machine learning that we have developed."

In addition to extreme conditions, devices in orbit, such as satellites, are also threatened by collisions with space debris. Most of these devices are equipped with heavy shields to protect them, which add significant weight to the object, requiring more power to support it.

"The longer autonomous devices operate in extreme conditions, the more energy they require to perform," Tomar said. "The current voltage capacity for batteries in space is very low and they require solar energy to recharge. Our approach, based on a combination of cloud and edge computing, will enable devices, such as satellites, to operate in darker places for longer and to store more charge so they can perform more operations."





EXPERTISE FOR A
BREAKTHROUGH

Ultra-short duration plasma actuators hold promise

USING PLASMA ACTUATORS FOR FLOW CONTROL ISN'T NEW.

On the surface of an airfoil, they've been shown to prevent stall and reduce drag. Lower drag means using less fuel, making flight more cost-effective and reducing harmful emissions to the environment.

Most traditional approaches to plasma flow control are effective only at speeds much lower than typical flight speeds of commercial and military aircraft and at relatively small scales. A key challenge to making plasma flow control a practical solution is scaling the actuators and their effects to higher-speed, larger-scale flows.

Sally Bane, an associate professor in AAE, is leading the efforts of a multi-disciplinary team to design plasma actuators for controlling high-speed, turbulent flows. These actuators use ultra-short duration plasmas generated at high frequencies to produce localized heating and complex flow effects. They hold promise to be able to control the flow at low speeds as well as supersonic and hypersonic regimes, Bane said.

"We have expertise in all the areas needed to really understand how these control mechanisms work and to make a breakthrough in developing plasma actuators that can be used in practical high-speed flight," Bane said.

Bane is developing surface actuators that are non-intrusive to the flow, require no moving parts and can be tailored in terms of the geometry of the plasma and the localized heating and flow effects. Then, she's testing the actuators in a wide regime of flow regimes, made possible by Purdue's various wind tunnel facilities.

A handful of experiments, including in Bane's own lab, have shown that actuators based on ultra-short pulsed plasmas can have control authority even in supersonic flows. In addition to controlling subsonic flow for drag reduction, the actuators also may be effective in controlling shock waves and other compressible flow phenomena. Shock wave boundary layer interaction is a pervasive phenomenon in transonic, supersonic and hypersonic flows, leading to detrimental effects like unsteady loading on structures and dramatically increased heat transfer.

"We're interested in using these actuators to try to control such flow phenomena to mitigate the harmful effects," Bane said. "But nobody understands yet why these actuators have this control authority. Other researchers have tested actuators in supersonic flow and shown that, yes, we can control a shock wave. But we don't truly understand how that works. So we're taking detailed measurements of the plasma and the flow to try to better understand the underlying physics.

"We cannot optimize the actuators and their operational range unless we understand how they are actually controlling the flow."

To do this, Bane is taking advantage of Purdue's wide expertise on plasma physics, aerodynamics and advanced flow diagnostics.

In the areas of plasma physics and plasma-based flow control, Bane works with AAE Professors Jonathan Poggie and Sergey Macheret and Assistant Professor Alexey Shashurin, all members of Purdue's Cold Plasmas Preeminent Team. Bane also collaborates with several faculty in mechanical engineering on advanced flow diagnostics and modeling of high speed and non-equilibrium flows, including Professors Terrence Meyer and Guillermo Paniagua and Assistant Professor Carlo Scalo, who all have courtesy appointments in AAE.

The research tackles the problem with a wide variety of test platforms and diagnostics, including the supersonic wind tunnel at the Aerospace Sciences Laboratory and Paniagua's Purdue Experimental Turbine Aero-thermal Laboratory at Maurice J. Zucrow Laboratories.

"To really understand how to harness plasma actuators for effective and efficient aerodynamic flow control, we need to have an understanding of plasma physics, fluid dynamics and plasma-fluid coupling, and we need to have the ability to measure and model these things," Bane said. "We have all those capabilities here."

"WE HAVE EXPERTISE IN ALL THE AREAS NEEDED TO REALLY UNDERSTAND HOW THESE CONTROL MECHANISMS WORK AND TO MAKE A BREAKTHROUGH IN DEVELOPING PLASMA ACTUATORS THAT CAN BE USED IN PRACTICAL HIGH-SPEED FLIGHT."

- SALLY BANE

AAE Associate Professor Sally Bane (Rebecca McElhoo/Purdue University)

NEW REPORTING TOOL COULD PREVENT ACCIDENTS, SAVE LIVES

FORM TAKES DEEPER DIVE INTO CAUSES OF HUMAN ERROR

Despite efforts to mitigate runway incursions — when an aircraft is on a runway when it is not supposed to be there — their number continues to grow. On average, five incursions occur each day in the United States, according to the Federal Aviation Administration. Most of those are near-misses or incidents and did not result in injuries or aircraft damage.

But with airport surfaces getting more crowded, a small error can have serious consequences. Even though human error is a major contributor to incursions, researchers still are unsure of the causes of human error. There is a need for better quality of runway incursion data to help identify these causes before a serious accident.

A new reporting tool developed by AAE PhD candidate Divya Bhargava and Professor Karen Marais is aimed at providing a way of improving data collection.

“With detailed information on human error and its causes, the industry can develop evidence-based preventive measures. These targeted measures can help reduce human error, leading to fewer incursions, ultimately leading to preventing accidents and saving lives,” Marais said.

In the U.S., trained investigators at the National Transportation Safety Board investigate aviation accidents but not most incidents, including incursions. Incursion incidents are reported by the air traffic controllers on duty at the time of incursion to the FAA. The current reporting form asks where the incursion occurred and who was involved and also includes an open-ended question asking controllers to describe the incident. Some fill in only a couple lines, others a paragraph. Controllers may not be aware of the causes of errors or may not consider reporting more than only a description of the incident. As a result, reports often explain *what* happened but not *why*.

But if they were directed toward specifics — what happened (which aircraft were where, and when), how it happened (e.g., the controller gave the wrong instruction) and why it happened (e.g., the controller was fatigued) — then perhaps more effective measures could be developed to reduce incursions by helping controllers create better reports.

“We want to encourage them to, in a way, conduct mini-in-

vestigations on their own,” Bhargava said. “They may not always consider looking deeper into the incident and reporting all the contributing factors. But if in our form, if we have a question that specifically asks, ‘Why do you think the pilot made this error?’ Then does that prompt them to go talk to the pilot and give us more information?”

That’s what Bhargava is hoping, and she’s been encouraged by initial conversations with controllers who say they want to help make aviation safer and would welcome a form that’s more descriptive.

Even though pilots in commercial aviation have far more technology to improve their situational awareness than their counterparts in general aviation, incidents still are happening. The motivation for this research is to identify why humans are making the errors.

“You can be given all the resources that you need, at the end of the day, it’s the human brain that’s making those decisions,” Bhargava said. “What is going on in their heads? How are they making these decisions? You don’t go out saying you’re going to cause a runway incursion. But you make some decisions at that time and you think those decisions are right. We want to understand the factors that contributed to the decision-making.”

Bhargava will create a hypothetical runway incursion incident and ask flight controllers to report it. One group will use the current form, the other will use the new tool. Based on the results of the experiments with controllers, Marais and Bhargava may recommend steps to further improve the tool. They also would like to share them with the FAA, perhaps inspiring improvements to the current reporting system. The research was originally inspired by an FAA grant through the Partnership to Enhance General Aviation Safety, Accessibility and Sustainability, the FAA Center of Excellence for general aviation, in which Bhargava and Marais investigated the causes of runway incursions in the general aviation community.

“Will my form be the ultimate solution? Maybe not. But it may be a step,” Bhargava said. “It’s going to be a study where we may say, ‘OK this is one way that you can get more information,’ and that will provide the foundation for the next version of the form.”



*Professor Karen Marais and AAE PhD candidate
Divya Bhargava (John Underwood/Purdue University)*

MISSION MATTERS

LASER IGNITION
COULD SPARK
RETURN TRIPS

A/E Assistant Professor Carson Stabrough (Retha McElroy/Purdue University)

The 60 million-kilometer trip back from Mars starts with a nanosecond laser ignition pulse. And without a vehicle carrying tanks of toxic hypergolic propellants.

At least that's what Carson Slabaugh, an assistant professor in AAE, and a team of engineers, applied mathematicians and computer scientists are proposing by burning methane and oxygen with an ignition source that not only can be used many, many times but also can effectively recharge by sitting in the sunlight on the surface of the planet.

"At the end of the day, the choice of methane and oxygen is definitely relevant to this long-term vision for Mars return trips. This propellant combination has benefits in terms of performance, simplicity and reusability that make it a good choice for lander ascent missions," Slabaugh said. "You can also find the things you need on the Martian surface and in the Martian atmosphere to manufacture these propellants and fuel the liquid rocket engine. Combine that idea with this ignition source ... and all that starts looking like a believable narrative."

Stanford University is leading the project, funded by a \$16.5 million grant from the Department of Energy through the National Nuclear Security Administration's Predictive Science Academic Alliance Program, and will conduct all computational work. Slabaugh is Purdue's lead principal investigator, and Robert Lucht, the Ralph and Bettye Bailey Distinguished Professor of Mechanical Engineering, who has a joint appointment with AAE, is a co-PI. All of the experiments will be conducted at the Maurice J. Zucrow Laboratories, where Lucht is director.

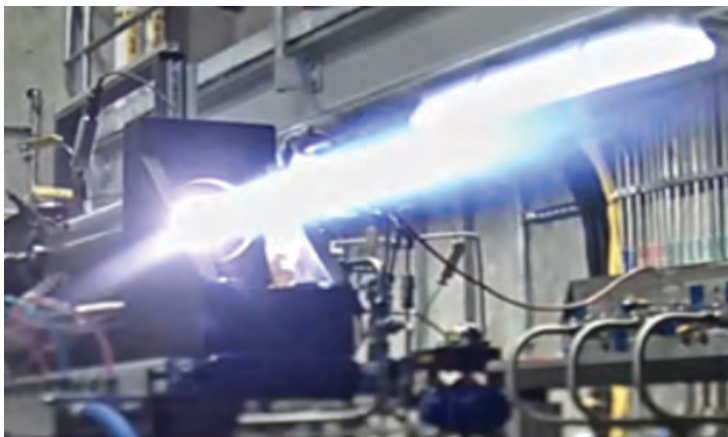
"We're unique at Zucrow in our ability to do things like this, especially as an academic lab," Slabaugh said. "The experiments will have many variables that must be controlled with surgical precision or the results will be impossible to interpret."

At Zucrow, Slabaugh will inject liquid oxygen and gaseous methane into a rocket combustion chamber at low initial pressures to simulate the vacuum of space and then deliver a precisely timed pulse of laser radiation. The electromagnetic field will break down the fluid into a plasma, and the plasma will cause a chemical reaction.

The laser allows a focused application of the ignition energy to a region that has the ideal mixture for combustion, away from walls that could burn up. Conventional igniters in rocket combustors are bulky and must be installed wherever they can fit on the combustor. There is a competing effect of getting the ignitor energy to the propellants but keeping the flame away from parts that could also burn up. But a laser allows the ignition energy to be put where it's needed.

"Because of that, you only need a small fraction of it, you don't have to overwhelm the system," Slabaugh said. "Power requirements for laser ignition can be a lot lower because you can put that ignition kernel, that plasma kernel, in the flow where the mixture is at the right conditions."

Hypergols burn as soon as they come in contact with each other under any conditions, and those toxic propellants then have to be carried on the spacecraft in tanks. If the chamber needs to be ignited again — or numerous times on a very long space mission— that means the vehicle needs to carry more



Slabaugh and his students have tested methane-oxygen rocket engines in his lab at the Maurice J. Zucrow Laboratories. (Photo provided)

of that propellant on the mission. That adds mass, too, which means less payload.

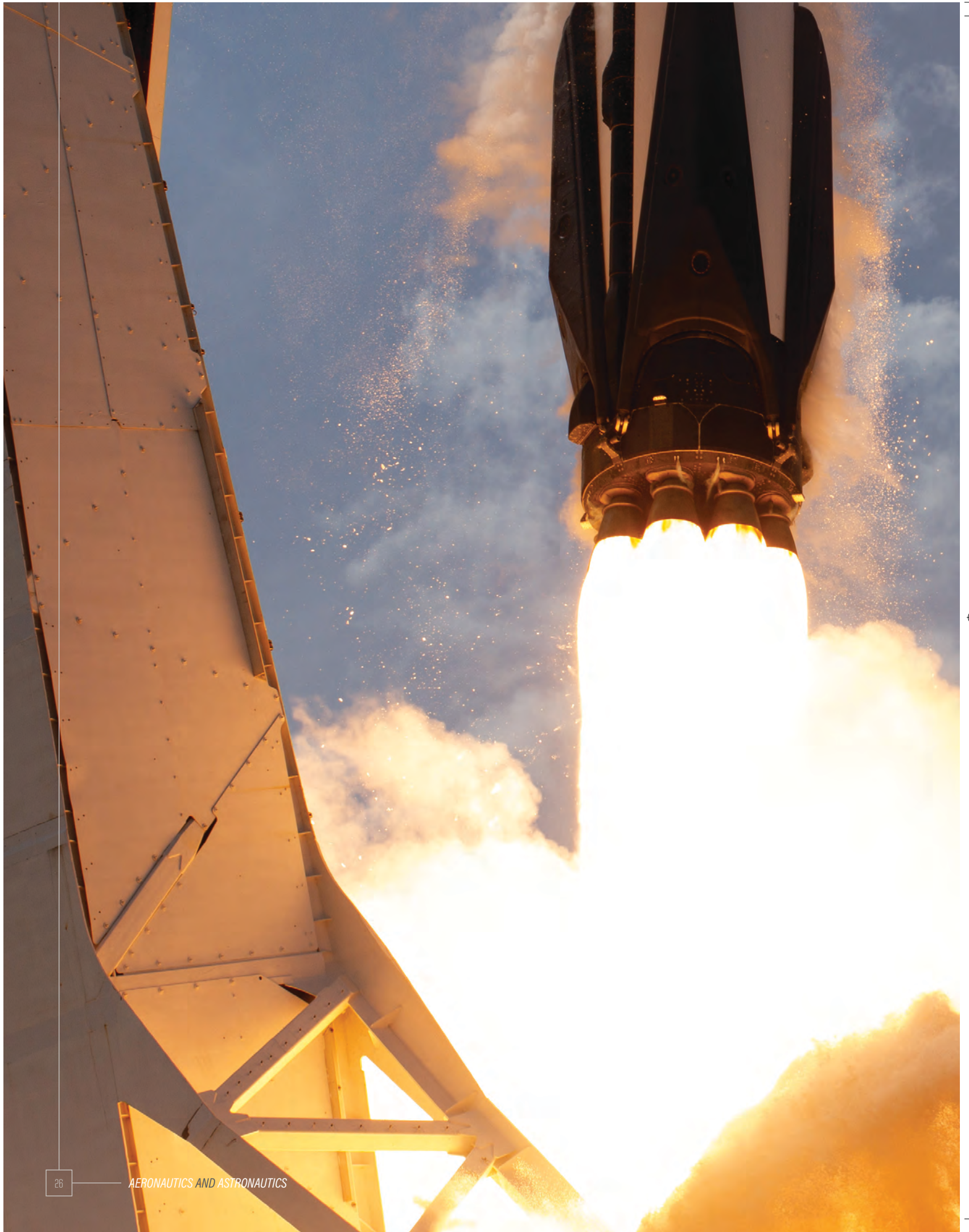
That's the current approach for space exploration. But it's a process that makes some sort of electronic form of ignition look more favorable. Solar panels could be taken to recharge batteries and also be used for whatever other electronics are needed on the mission, a mass benefit if the supporting infrastructure is common between the ignition system and other things.

The idea of laser ignition initially was explored by a team in Germany for this application, which demonstrated it was possible in the same flows and propellants Slabaugh's group is interested in. But the German Aerospace Center took an applied direction. This research aims at taking it back to fundamental roots and doing a more detailed experimental characterization, Slabaugh said.

"The real interest comes back to the motivation for the whole program, which is predictive science. Can we take a process that involves propellant injection, evaporation and mixing within the interaction region of a supersonic flow of methane with a stream of liquid oxygen droplets, hit that with this high irradiance electromagnetic field and then predict the chemically reacting flow evolution?" Slabaugh said. "There are so many coupled processes with stochastic elements that it just makes the prediction seem intractable. But it all comes back to deterministic governing equations, so it should be feasible."

Zucrow can run experiments with liquid oxygen at real rocket propellant flow conditions, a one-of-kind capability for a university. Slabaugh will run his tests in the High Pressure Combustion Lab, next to the facility's laser lab, which will enable the laser ignition component of the work and the measurements that he and Lucht will take.

"The infrastructure at Zucrow is most certainly a source of pride for us, but I think at least equally important is that the people at Zucrow Laboratories are there to use it and are not afraid to go after problems like this, that have a ton of uncertainty and a lot of risk and, frankly, if you're not used to it like we are, can be quite terrifying," Slabaugh said. "It's a lot to take on. We only work on problems that are worth working on. This is a pretty challenging one. It'll be cool."





FUELING THE FUTURE OF SPACE EXPLORATION

**HISTORIC SPACEX LAUNCH, POWERED BY
ALUMNI, INSPIRES NEXT GENERATION**

A SpaceX Falcon 9 rocket, carrying the company's Crew Dragon spacecraft, launched May 30, 2020, from Launch Complex 39A at NASA's Kennedy Space Center in Florida. NASA's SpaceX Demo-2 mission to the International Space Station had two astronauts onboard, the first time since 2011 American astronauts launched on an American rocket from American soil to low-Earth orbit. (Joel Kowsky/NASA)

Calvin Phillips fell asleep each night as a kid, tucked tightly underneath the covers on a bed that looked like a rocket ship, dreams shifting between the space camp he'd just attended or the air and space museum he'd visited that day or visions still fresh from a trip to the planetarium.

By his ninth-grade science fair, Phillips suggested building a rocket. High school firmly solidified his aerospace engineer aspirations, and there was no stopping his passionate pursuit.

A pursuit that led him to internships at NASA Langley and Johns Hopkins University Applied Physics Laboratory as an undergraduate at Georgia Tech.

That led him to Purdue and the School of Aeronautics and Astronautics in 2019 as a graduate student.

That led him to an internship with The Aerospace Corporation in 2020, as part of the Matthew Isakowitz Fellowship program.

That led to sitting atop a van, parked on a bridge over the Indian River in Titusville, Fla., in late May 2020.

That led to unashamed tears when he watched the glorious launch of SpaceX's Falcon 9 rocket, carrying its Crew Dragon capsule, headed for the International Space Station.

That led to cork popping and champagne flowing to celebrate the first launch since 2011 from United States soil to send U.S. astronauts to the ISS.

As the folks who lined the A. Max Brewer Memorial Parkway chanted "U-S-A," Phillips' mind churned as tears flowed.

"When I saw that rocket go off and I could feel the rumble, I saw where my future was headed and all the insane hard work that my colleagues have put into making that moment happen," Phillips said. "I felt very overwhelmed knowing how far I had come to be standing there that day and how much further I need to go."

Phillips is in the right place to forge ahead and, ideally, achieve new heights. If it wasn't clear

before that late-May launch, it has been validated since: Spurred by faculty who cultivate discovery-seekers and explorers and equipped state-of-the-art facilities, an AAE education prepares students to contribute to historic feats.

"I believe that it is a combination of the incredible workload we take on in AAE and the expertise that you can't find anywhere else," Phillips said. "I took equivalent courses at other schools, and none of them compared to how much I learned under the Purdue faculty. During my summer experience, I would say close to 70 percent of the knowledge I needed to be successful was learned at Purdue AAE. It really is a special place we have."

Phillips' dreams aren't the first to be nurtured by an AAE education. That jubilation he felt on the bridge that May day? That spread much wider.

It reverberated from the walls of SpaceX's headquarters in Hawthorne, Calif., and inside NASA's mission control in Houston, partners on the mission that'd been years in the making, since the government started aligning with commercial space companies to send Americans back to space on rockets made by Americans, launched from America.

With the successful completion of the Demo 2 launch and capsule recovery, the U.S. regained a capability to transport astronauts to orbit without reliance on the Russian Soyuz vehicle, which had been the astronauts' only ride to and from the ISS since NASA's space shuttle fleet was grounded nearly a decade ago.

And AAE was significant in establishing that new phase of space exploration.

Alumni touched nearly every aspect of the mission. At least 24 contributed on the SpaceX side from locations at the launch complex at Cape Canaveral,



(Joel Kowsky/NASA)

Fla., the engine/stage testing complex in MacGregor, Texas, and in Hawthorne, said Stephen Heister, the Raisbeck Engineering Distinguished Professor for Engineering and Technology Integration.

“The School of Aeronautics and Astronautics is proud of our alumni’s contributions to the historic mission and to the success of SpaceX in becoming the world’s premier launch provider,” Heister said.

Those alumni — or even Phillips — won’t be the last to make an impact.

AAE will continue to push exploration, with ideas and innovation. Continued growth in computational power, advanced manufacturing technologies and global demands for internet connectivity are fueling tremendous investments in launch propulsion technology, Heister said.

“The School is contributing to this growing demand through space-related research and via the human capital we provide with our talented graduates,” he said.

Having constant access to ISS and orbit in general provides unique opportunities, too, AAE Professor Steven Collicott said. The commercial crew operations should enable greater focus by NASA on new steps in exploration, such as the moon and beyond, and commercial space activity will continue to flourish.

SPACEX & AAE

More than 20 AAE alumni are known to have contributed to NASA's SpaceX Demo-2 mission in May 2020 at SpaceX's various facilities: Pamela Berkowitz, Michael Bedard, Jeremy Corpening, Alix Crandell, Drew Damon, James D'Entremont III, Jon Edwards (OAE), William Gerstermaier (OAE, DEA), Thaddaeus Halsmer, Mark James, Paul Juska, Brandon Kan, Kenton Lucas, Kevin Miller (OAE), Enrique Portillo, Sam Rodkey, Reuben Schuff, David Schulz, David Stechmann, Matt Steiner, Steven Stoot, Erik Susemichel, John Tsohas and Jared Willits.

“Perhaps our current students will become not only the engineers designing and launching commercial human vehicles to space but also may become commercial astronauts in them. Or in commercial sub-orbital rockets, too, performing research in space after a breakfast at home and before a dinner at home the same day,” Collicott said. “I see many really cool opportunities now and in the future for our students.”



LIMITING THE MESS ON THE WAY TO THE MOON

CISLUNAR INITIATIVE TAKING STEPS TO SOLVE CHALLENGES

Space Situational Awareness (SSA) — the knowledge and information of all objects, active satellites and space debris (sometimes called space junk) — and Space Traffic Management (STM) — the engineering solutions to coordinate objects in space — have been focused on the near-Earth region so far. This is the region up to altitudes of 36,000 kilometers above the Earth’s surface.

The cislunar region, expanding out all the way to the moon, primarily has been used for scientific missions. However, there is a recent push for more missions, scientific and commercial. One of which is NASA’s Lunar Orbital Platform-Gateway (LOP-G), a planned module comparable to the International Space Station (ISS) but far out in space, in the region between 3,000 and 70,000 kilometers from the lunar surface. This creates the new need for SSA and STM to expand out to the cislunar region as well.

“The near-Earth is clogged with satellites and space debris because satellites were and are launched in a more or less haphazard approach, which is creating many problems. For the cislunar space, we have to be much smarter. And this time we have the chance to be ahead of the game,” said Carolin Frueh, an associate professor in AAE who is the chair of COSPAR PEDAS, the Committee on Space Research’s Panel on Potentially Environmentally Detrimental Activities in Space, an international group dedicated to ensuring sustainable use of space.

“But cislunar space is also very different. We cannot just copy paste what is done with junk in the near-Earth space.”

The Purdue Engineering Initiative in Cislunar Space, launched in July 2019, aims to take a leadership role in the development of cislunar space. Through exploration and discovery, the initiative is working to expand access to space, identify and utilize space resources, advance the development of space



AAE Associate Professor
Carolin Frueh (Rebecca
McElhoo/Purdue University)

policy and grow the cislunar economy. Frueh is the lead for Space Traffic Management within the Cislunar Initiative.

One key difference between cislunar space and the near-Earth region is the dynamic environment. Satellites in the near-Earth region are captured and stay in an orbit around the Earth. The cislunar region has more influence from other celestial bodies.

“It is not quite like *Space Odyssey* with the vortex, but nevertheless, a small deviation in the orbit can lead you into a very different orbital region, ending up far from where you started or eventually wanted to be,” Frueh said.

This presents new challenges, such as in the prediction of collisions between spacecrafts with each other and/or space junk. Another challenge is the large distances. Ground-based observation stations, such as the Purdue Optical Ground Station (POGS), Frueh’s telescope, are no longer sufficient. They need supplements by lunar ground-based observation stations and space-based telescopes mounted on satellites.

The design of such a network that would allow observations and awareness in the complete vast cislunar space and new methods for gauging and predicting collisions in the very different cislunar environment are two of the challenges Frueh is working on with her group.

“It is exciting to collect information and provide solutions for objects as far as the moon with no initial information; those objects can be space debris but could also be satellites from other nations,” Frueh said.



POURPOINT APPOINTED CO-CHAIR OF CISLUNAR INITIATIVE

AAE Professor Timothée Pourpoint was appointed co-chair of the Purdue Engineering Initiative in Cislunar Space in June 2020. He serves with co-chair Kathleen Howell, the Hsu Lo Distinguished Professor of Aeronautics and Astronautics.

Pourpoint is a leading expert on propulsion systems and experimental testing for propul-

sion research and development. He joined the AAE faculty in 2005.

In his role with the Cislunar Initiative, Pourpoint succeeded David Spencer, who left his position as associate professor in AAE to become Mars Sample Return Campaign Mission manager at the NASA Jet Propulsion Laboratory.



*AAE Professor Daniel DeLaurentis
(John Underwood/Purdue University)*

HUGE

POTENTIAL

ADVANCED AIR MOBILITY IN URBAN, REGIONAL SETTING
PROMISING PATH TO IMPROVING PRODUCTIVITY

For more than 15 years, William Crossley and Daniel DeLaurentis have been bringing system-of-systems methodology to complex, multi-faceted transportation problems, especially involving new air vehicles.

They have different “flavors,” DeLaurentis said, but Crossley inspired and recruited DeLaurentis, who was hired as part of the system-of-systems signature area in 2004.

No wonder the pair of AAE professors was approached to spearhead research investigating regional and urban systems for advanced air mobility, in partnership with NASA through the National Institutes of Aerospace.

The first phase of the work included building computational tools to examine regional mobility with advanced conventional takeoff and landing airplanes and exploring how those new airplanes — leveraging existing ground transportation, ride sharing, electric propulsion and autonomy — could be part of an improved regional transportation system.

After finishing that study, Crossley and DeLaurentis were asked to take a step shorter than the regional system and build a computational model to explore specifically what might be some of the important and less-considered operational limits or reveal unknown operational limits to an urban air mobility (UAM) system.

The system-of-systems view of on-demand mobility is ideal for this kind of study that is about much more than new innovative vehicles but also factors in weather, technology, operational constraints, peak traffic conditions and infrastructures, among other things. The pair explores operational limits by applying the Resources, Operations, Policies, Economics (ROPE) table methodology.

“The potential here, in terms of improving mobility and connecting people, is huge,” said Crossley, the J. William Uhrig and Anastasia Vournas Head of Aeronautics and Astronautics. “Using aircraft to move people where they need to be quickly, safely and efficiently in an urban or regional setting is a promising path to improving productivity and quality of life. Our work to uncover potential operational limits for UAM will help provide a transportation solution that works, not just an aircraft that can perform a mission.”

Crossley and DeLaurentis selected two metropolitan areas, Dallas and Chicago, to study operational questions. The cities had a nice mix of similarities but also differences, like weather and public transportation options. Initial results suggested the number of aircraft that can take off and land at a “UAM Aerodrome” may be a bigger limit than anticipated. Another interesting outcome was when Crossley and DeLaurentis con-

sidered the potential total CO2 emissions impact of introducing electric vertical takeoff and landing aircraft in the two cities. Given that the Chicago area electric power generation has a higher percentage of nuclear power plants than Dallas, the effective CO2 emissions are much lower in Chicago than in Dallas.

The timing of a deep dive into advanced air mobility certainly makes sense. Companies like Uber have shown ride-sharing on the ground is viable, and there’s been an increased improvement of aircraft technology. There are more than 200 aircraft concepts in different stages of development to perform UAM missions. So an electric-powered, four-person vertical take-off and landing vehicle seems more plausible now than ever.

“There is quite a bit of interest and excitement in this potential,” Crossley said.

NASA sponsored a study in February 2020, undertaken by the Committee on Urban Air Mobility Research and Technology that included DeLaurentis, through the National Academies of Sciences, Engineering, and Medicine. The report recommended NASA should team with the Federal Aviation Administration, industry and academia to research the full effects that increased unpiloted air vehicle traffic could have on society.

The search for answers and information won’t end soon. Crossley and DeLaurentis are hoping their study will help provide both.

“Our collaborative work with NASA examines the problem holistically so that, beyond the hype and optimistic guesses from technologists, we seek out the hidden barriers that must be overcome to reach success. Because you’d hate to waste a couple billion dollars of everyone’s money on something that’s kind of a flop,” DeLaurentis said with a laugh.

Though DeLaurentis appreciated the time spent and work done by the Committee for NASA — and the 82-page report it generated — his project with Crossley has been especially rewarding: It is ideally in the DeLaurentis wheelhouse.

“Ever since I was a baby grad student, I’ve been an aerospace vehicle design kind of guy. It’s hard to find a better overlap with my general interests, which are in these large complex system-of-systems problems from a methodology point of view, and then with my hat as a design guy,” he said. “So this has all the combinations of a really juicy system-of-systems problem and a new aircraft. Those kind of combinations of the undefined future with all those elements are what really excite me.”



*William Crossley
(John Underwood/
Purdue University)*



NASA ULI GRANT TACKLES CHALLENGES OF ADVANCED
AIR MOBILITY

'SECURE AND SAFE ASSURED AUTONOMY' FOCUS OF PROJECT



Without physical space to build more roads as population in urban areas continues to grow, developing a novel integration of secure and safe autonomous systems used on unmanned Advanced Air Mobility aircraft is imperative.

AAE researchers are examining a range of technical areas to tackle the problem and support NASA's aeronautics research goals as part of a multidisciplinary grant through the University Leadership Initiative program, the largest university funding project from NASA on the aeronautics side. North Carolina Agricultural & Technical State University is the overall lead on the four-year, \$8-million collaboration with Purdue and Georgia Tech, as well as industry partners.

With the ULI, universities were asked to present a compelling investigation that addressed a technical challenge of the strategic research thrusts of NASA. Purdue's group targeted the "secure and safe assured autonomy" thrust with four specific technical challenges: Safe Perception, Coordination, Planning and Navigation; Secured Autonomy; Verification and Validation and Test and Evaluation; and System Integration.

AAE's work will be concentrated on three of those challenges, focusing on innovations in secure and robust distributed autonomy and control algorithms applicable to both cargo and future passenger carrying advanced air mobility, as well as system-of-systems integration simulation and analysis of the independent technologies.

In "Secured Autonomy," AAE Professor Inseok Hwang is the lead, AAE Associate Professor Dengfeng Sun is co-lead and AAE Assistant Professor Shaoshuai Mou is a supporting faculty member. They'll tackle mathematical modeling of Urban Air Mobility (UAM) and cyberattack; cyberattack analysis, detection and risk management; AI-driven cyberattack monitoring; and benchmark resilience in fully distributed scenarios.

The control systems and the autonomy algorithms must be robust — secure — against different forms of cyber-security threats.

"Future air transportation systems, such as UAM, are large-scale and complex systems with integrated logical, or cyber and physical elements," Hwang said. "Conventional security techniques alone will not assure their security and safety, while traditional fault-tolerant control methods are not directly ap-

plicable to achieve resiliency against malicious cyber-physical attacks with sophisticated spoofs of the monitoring system.

"In this project, we plan to address challenges for secured air transportation systems that come from the inherent heterogeneity of their components, the large scale and limited computation/processing capability of their individual components and the hostile, highly dynamic environment."

James Goppert, a visiting assistant professor in AAE, is involved in the third technical challenge, which could include computerized testing as well as experiments. Some of which could be performed in AAE's UAS Test Facility, a space approximately 20,000 square feet and 35-feet high, equipped with a motion capture system located within Hangar 4 at the Purdue Airport.

The indoor motion capture system, installed and first used in Spring 2020, is the largest in the world. It allows unique experiments, such as flying fixed-wing aircraft and large swarms, that could not be accommodated in smaller motion-capture facilities. Virtual reality and augmented reality can be used to construct environments that would be too dangerous or laborious to build in real life, and it can simulate harsh environments such as wind gusts, GPS jamming and cyberattacks. For the ULI research, it will be used to develop and validate algorithms for safe and robust operation of UAM vehicles and UAS Traffic Management. The motion capture system will provide ground truth data and a mixed reality environment recreating cluttered urban environments.

"We are looking forward to leveraging the state-of-the-art UAS Test Facility to solve challenging problems for the next generation National Airspace Systems and inspire the next generation of engineers to pursue careers in autonomy," said Goppert, the acting managing director for the facility.

The facility also will come into play on another piece of the project: Offering hands-on research for students. In Fall 2020, Goppert taught an interdisciplinary Vertically Integrated Projects (VIP) Program course that was connected to the project. Goppert will continue to offer a VIP course that is based at the facility and will give students exposure to topics such as computer vision, embedded systems, software verification and cyber-security.

AAE Professor Daniel DeLaurentis, Purdue's principal investigator on the project, co-leads the system integration task, which could use some of the models he and William Crossley built for NASA for regional and urban systems to look at the integration of advanced algorithms in real vehicles (Page 33).

Advanced Air Mobility has many vehicle concepts and potential uses in both local and intraregional applications. (NASA)



SELF-SENSING MATERIALS 'DO MORE WITH LESS'

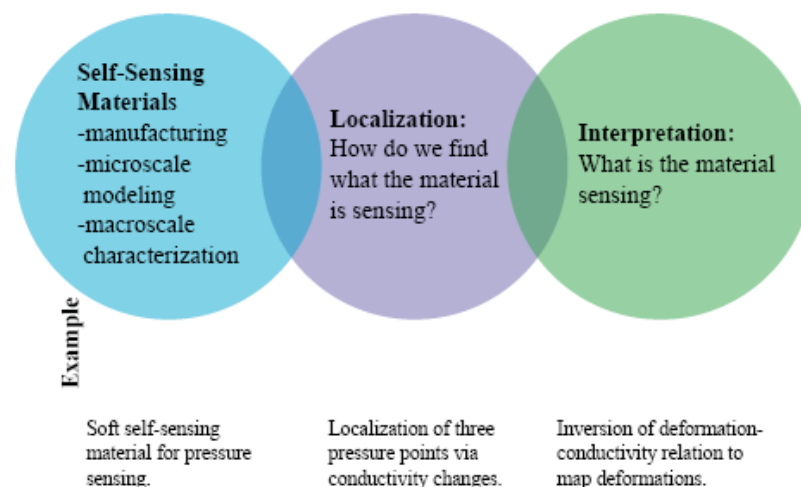
SEEKING COMPLETE
SENSING AUTONOMY

We expect a lot out of the materials we use. Because new technology is often limited by the materials available to us, there is a continual push for them to be lighter, stronger, more resilient, more adaptable and better able to perform in extreme environments or under extreme conditions. This push also transcends disciplines — aerospace, mechanical, civil, biomedical and electrical engineers all want materials that can “do more with less.”

Enter multi-functional materials. Also known as *smart* materials, these are so-named because they are capable of serving multiple purposes. That is, they have secondary — and sometimes tertiary — capabilities beyond their primary function. With this unique class of materials, engineers are able to, for example, design structures capable of load-bearing while simultaneously harvesting vibrational energy and converting it to usable electrical energy, produce composites capable of autonomously self-healing damage or even build wing profiles that can change their shape in order to adapt to evolving flight conditions. Multi-functional materials therefore truly embrace the do-more-with-less philosophy. Consequently, they have much potential to reduce size, weight and power consumption while simultaneously improving efficiency, safety and versatility by replacing several single-functionality systems with one multi-functional system.

My work predominantly focuses on a subset of multi-functional materials known as self-sensing materials. These materials are designed to feel, or sense, changes in temperature, pressure, pH or deformation among other external stimuli. In this way, self-sensing materials act like the nervous system of the structure or component in which they are embedded by allowing for intrinsic perception of condition. This is in stark contrast to traditional sensing approaches that rely on ad hoc networks of external sensors. In other words, in self-sensing materials, the material *is* the sensor. My specific approach to this is to design the material to have stimulus-responsive electrical properties such that changes in electrical properties act as an indicator of condition. This basic idea is very broadly translatable across disciplines — my team has explored self-sensing materials in applications such as fiber-reinforced structural composites, soft polymers for tactile and pressure sensing, additive manufacturing for on-demand and customizable printed strain sensors and bone cement for use in total joint replacement surgeries. We are even beginning work with collaborators to explore cementitious self-sensing materials for use in civil infrastructure.

Beyond just using self-sensing materials in these applications, we are also keenly interested in localization of artifacts and precisely quantifying the spatially distributed state of the material by inverting the stimulus-property relation. That is, we want to know what exactly the material is sensing and where it is sensing it. For this, we are developing multi-scale and multi-physical stimulus-property constitutive relations and working with collaborators to invert these relations via machine learning techniques such as deep neural networks. The ultimate goal of this work is complete sensing autonomy — materials intrinsically capable of sensing, localizing and precisely characterizing their health and condition. —TYLER TALLMAN





USING AEROSPACE TO FACILITATE NEW OPPORTUNITIES

*AAE Assistant Professor Tyler Tallman
(Rebecca McElhoe/Purdue University)*

HOWELL HONORED BY ALMA MATER



Iowa State University has bestowed its Distinguished Alumni Award, the highest honor for graduates, on Kathleen Connor Howell.

Howell, who received a bachelor's in aerospace engineering from Iowa State, is part of a three-member class that initially was to be recognized during a ceremony in April 2020. Because of COVID-19, the ceremony was rescheduled for April 2021.

Howell, the Hsu Lo Distinguished Professor of Aeronautics and Astronautics, will be recognized "for pioneering advancements in celestial mechanics and astrodynamics, mentoring a generation of highly regarded researchers and providing distinguished leadership and service to Purdue University."

"I was surprised and very humbled by this honor," Howell said. "My technical roots are at Iowa State University, where I was challenged and encouraged by the excellent faculty to pursue my goals. The learning and growing accomplished during my undergraduate years were also enabled and supported by the institution and the enriching environment."

HOWELL HONORED BY IAF

Howell was recognized by the International Astronautical Federation with a Distinguished Service Award for "outstanding competence and continuous dedication to the IAF Astrodynamics Committee and Astrodynamics Symposium for over 20 years."

The award, which had seven recipients in 2020, is intended to reward active volunteers for their distinguished service to the activities of the IAF.

SHIH HONORED BY AIAA



AAE Professor Tom Shih received the 2020 American Institute of Aeronautics and Astronautics (AIAA) Thermophysics Award, presented for an outstanding singular or sustained technical or scientific contribution by an individual in thermophysics, specifically as related to the study and application of the properties and mechanisms involved in thermal energy transfer and the study of environmental effects on such properties and mechanisms.

Shih was selected "for significant contributions in the development and application of computational design tools for the thermal management of gas turbines to improve efficiency and service life."

QIAO ADDED TO BOARD

AAE Professor Li Qiao started a six-year term on July 17, 2020 as one of eight new members on The Combustion Institute's Board of Directors.

As a member of the Board for the international nonprofit, educational and scientific society that promotes and disseminates research activities in all areas of combustion science and technology, Qiao will be responsible for making decisions that will guide the future of The Combustion Institute while addressing the needs of its international community.

NEW FACULTY FOR 2020

In Fall 2020, Ran Dai joined AAE as an associate professor in the autonomy and control group, and Dianyun Zhang joined as an assistant professor in structures and materials.

Dai's research focuses on control of autonomous systems, numerical optimization and networked dynamical systems. Her group has developed real-time optimal control algorithms for decision making and path planning of autonomous systems, especially for unmanned ground and aerial vehicles.

Zhang's broad area of research interest is in experimental characterization and computational modeling of lightweight materials, including polymer matrix composites, ceramic matrix composites and bio-inspired materials.

Brandon Chynoweth was added in as a research assistant professor in June 2020 to lead the design and construction of the Purdue University Mach 8 quiet tunnel.

PROFESSORS NAMED AIAA ASSOCIATE FELLOWS

Dengfeng Sun, an associate professor, and Joseph Jewell, an assistant professor, were selected in October 2019 as part of the Class of 2020 of Associate Fellows by the AIAA.

Sun's research areas include theory and application of control and optimization in aerospace engineering, particularly for networked dynamical systems such as air transportation and unmanned aerial vehicle systems. Jewell's research interests are primarily in experimental fluid dynamics, especially hypersonic aerothermodynamics.

FACULTY PROMOTIONS

Five AAE faculty members had promotions approved by Purdue University's Board of Trustees in April 2020 and were effective August 2020. Karen Marais, Jonathan Poggie and Qiao were promoted to full professor. Carolin Frueh and Haifeng Wang were promoted to associate professor.

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

ALUMNI NEWS

ICYMI



O'HARA ADDED TO NASA'S ASTRONAUT CORPS

Loral O'Hara is an adventurer in every sense.

She seeks out unique and daring opportunities and finds herself oddly comfortable, at peace even, in uncomfortable situations.

"In order to go cool places and explore and see new things, generally, it often involves being a little bit uncomfortable," O'Hara (MSAAE '09) said. "I like doing hard things in challenging environments."

What's next could be the most stunning opportunity yet.

In January 2020, O'Hara graduated from NASA's astronaut candidate program to its astronaut corps and is eligible for spaceflight. She could experience spacewalking outside the International Space Station with a sparkling, picturesque Earth in view, could practice bounding and leaping in low gravity on the moon as part of an Artemis mission, could even ultimately visit planets no other human has.

"I'm really excited," O'Hara said. "Just going to the different environments I've gotten to go to all over Earth has been pretty amazing. Getting to see so many unique places and special places on Earth, I can't wait to see them again from the vantage of space."

TORGERSON SELECTED AS DEA

William "Ted" Torgerson was honored as a Distinguished Engineering Alumni, an honor presented to men and women who have distinguished themselves in any field in ways that reflect favorably on Purdue University, the engineering profession or society in general.

At a banquet in February 2020, Torgerson (BSAAE '83, OAE '12) was recognized "for his consummate guidance leading multiple global teams in the development of advanced, next generation key military air vehicle technologies for the United States Air Force and Boeing."

As Boeing's senior director for program integration, Torgerson oversees the execution of the U.S. Air Force Advanced Pilot Training Program and the T-7A Red Hawk. Leading up to that role, he managed the development of Boeing's self-funded T-X aircraft and training system in partnership with Saab, including the development of the winning bid for the Air Force's next jet trainer program replacing the T-38C.



OAE CLASS SELECTED, EVENT RESCHEDULED

AAE hopes to honor its Outstanding Aerospace Engineer Class of 2020 in April 2021, after the initial banquet was postponed due to COVID-19. The class includes Douglas Adams, Christopher Clark, Darin DiTommaso, Douglas Joyce, Yen Matsutomi, Loral O'Hara, David Schmidt, Steve Slijepcevic and Rhonda Walthall.

ALUMNI AS FELLOW, ASSOCIATE FELLOWS

Ashfaq Adnan (PhD AAE '08) was named a Fellow of the American Society of Mechanical Engineers. Adnan is an associate professor in the Mechanical and Aerospace Engineering Department at University of Texas Arlington.

Matt Borg (PhD AAE '09) and Ben Linder (BSAAE '94, OAE '16) were selected as Associate Fellows by the American Institute of Aeronautics and Astronautics.

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

STUDENT NEWS

NDSEG FELLOWSHIP

AAE graduate students Derek Mamrol and Lauren Wagner were selected for the Department of Defense's National Defense Science and Engineering Graduate Fellowship Program.

The fellowship, established in 1989 and sponsored by the Army, Navy and Air Force, lasts for three years and pays for full tuition and all mandatory fees; a monthly stipend (\$38,400 annually); a \$5,000 travel budget over the fellow's tenure for professional development; and up to \$1,200 a year in health insurance.

Mamrol, whose advisors are AAE Professors Steven Schneider and Joseph Jewell, is studying how surface roughness on a hypersonic vehicle at an angle of attack can affect crossflow induced flow transition. His research aims to create metrics that engineers can use to determine what surface roughness is acceptable for flight vehicles.

Wagner, a PhD student, works with Purdue's Boeing/AFOSR Mach 6 quiet tunnel group to study experimental hypersonic boundary layer transition with co-advisors Schneider and Jewell. Her research focuses on studying the amplification of vortices as they travel across a separated flow region caused by a shock boundary layer interaction at Mach 6.

NSTGRO FELLOWSHIP

Nate Ballintyn, a graduate student in AAE, received a NASA Space Technology Graduate Research Opportunities (NSTGRO) fellowship.

NASA Space Technology Graduate Researchers will perform research at their respective campuses and at NASA Centers. Each student will be matched with a NASA subject matter expert who will serve as the student's research collaborator. The research collaborator will serve as the conduit into the larger technical community corresponding to the student's space technology research area, according to the program's website.

Ballintyn's research centers around the advancement of rotating detonation engines (RDEs), a powerful propulsion method with the capability to improve the performance of air-breathing and rocket engines. Ballintyn, whose advisor is Stephen Heister, the Raisbeck Engineering Distinguished Professor for Engineering and Technology Integration, is responsible for designing and testing a hypergolic rocket RDE with potential applications to orbital maneuvering, reaction control systems, planetary descent/ascent and deep space exploration.

NSF GRADUATE RESEARCH FELLOWSHIP

Ruth Ansley Beaver, Ryan Strelau and Paige Whittington received the oldest graduate fellowship of its kind, the prestigious NSF Graduate Research Fellowship Program. Established in 1952, the NSF GRFP recognizes and supports outstanding graduate students in NSF-supported science, technology, engineering and mathematics disciplines who are pursuing research-based master's and doctoral degrees at accredited U.S. institutions, according to its website.

The fellowship provides a three-year annual stipend of \$34,000, a \$12,000 cost of education allowance for tuition and fees and opportunities for international research and professional development.

Beaver started at Purdue in the fall, after completing her bachelor's at the College of William and Mary. There, she majored in physics with a concentration in engineering physics and applied design. At Purdue, under advisor Timothée Pourpoint, Beaver intends to research novel fuels, possibly hypergolic propellants and possibly a new configuration for solid fuels.

Strelau started his master's in Carson Slabaugh's research group in the fall. Strelau's research will be in propulsion, focusing on studying laser ignition in a rocket combustor designed for vacuum applications using a variety of advanced optical diagnostic methods.

Whittington, a master's student in AAE, will be performing research in astrodynamics by analyzing orbits and how to transfer between them in the Earth-moon system. A student in Kathleen Howell's research group, Whittington's research mainly will deal with the three-body problem in which an additional gravitational body is present. That presents additional difficulty because, unlike the two-body problem, there are no analytical solutions to the three-body problem. Through her research, Whittington will seek to reduce the uncertainty of orbit selection near the moon where orbital perturbations can be significant.

BILSLAND

Hashim Hassan, Logan Kamperschroer and Paul Witsberger were awarded the Bilsland Dissertation Fellowship. They were nominated by the AAE Graduate Committee and Awards Committee and selected by the Dean of Purdue's Graduate School. Each recipient will receive a base salary of \$20,000, a supplemental salary of \$7,000, a graduate tuition remission for up to two semesters and one summer session (approximately \$35,000) and an annual medical insurance premium contribution.

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

IN MEMORIAM

FULBRIGHT

Rachel Delmontagne (BSAAE '18) received a grant offer from the Fulbright U.S. Student Program for 2020-21. Delmontagne applied to teach English in Spain. Since her graduation in 2018, she has been working in Ghana, first with the Peace Corps, then as a math teacher. During her time as a student, she was a recipient of the Presidential Scholarship and the Navy Supply Corps Foundation Scholarship.

EARHART RECIPIENTS

PhD candidates Elizabeth Benitez and Jennifer Pouplin were among 35 Zonta International Amelia Earhart Fellowship recipients from 14 countries in 2020, and each will receive a \$10,000 fellowship.

For her PhD research under AAE Professor Steven Schneider and Assistant Professor Joseph Jewell, Benitez is studying traveling hypersonic instabilities related to an axisymmetric separation bubble. As part of the research, she has built a laser interferometer to work with the Mach 6 quiet tunnel to make high-speed off-the-surface measurements.

Pouplin is working with David Minton, a professor in Earth, Atmospheric and Planetary Sciences who has a courtesy appointment in AAE, on the formation of Martian moons.

1940s

Col. (Ret.) Charles C. Bock, Jr. (BSAE '49)
Walter C. Boldt (BSAT '49)
Seth E. Burgess (BSAT '49)
Glenn A. Hankins (BSAE '46)
Thomas F. Hanson (BSAE '49)
Harvey G. McComb Jr. (BSAE '48, MSESc '50)
Rogers H. Morrison, Sr. (BSAE '48)
D. Ross Osborn (BSAT '47)
Charles R. Reid (BSAE '49)

1950s

Col. Robert L. Alter (BSAE '50)
Robley E. Doyle (BSAT '50)
Robert K. Burgess, P.E. (BSAE '51)
John Selenko (BSAT '51)
Robert W. Sorenson (BSAT '51)
James E. Norem (BSAT '52)
Neil T. Bean (BSAT '53)
Hans K. Karrenberg (BSAE '54)
William F. Sanderman (BSAE '55)
Dale C. Ford (BSAE '56)
Ernest L. Hartman (BSAE '56)
Robert T. Hayes (BSAE '56)
Robert L. Henn (BSAT '56)
Robert N. James (BSAE '56)
Robert F. Knapp (BSAE '56)
Arend H. Reid (BSAT '56)
Thomas R. Titus (BSAT '56)
William R. Bolles II (BSAT '57)
Phillip H. Ambs (BSAE '58)
Joseph T. Cave (BSAT '58)

Luther M. Hays (BSAE '58)
Kenneth W. Schuning (BSAE '59)
William H. Woebkenberg Jr. (BSAE '59)

1960s

John O. Summers (BSESc '60)
David L. Schmutzler (BSESc '62)
Joseph J. Cox Jr. (MSAE '64)
David L. Furst (BSAE '64)
Ronald R. Clark (BSAE '62, MSESc '65)
Larry N. Lydick (MSESc '65)
George R. Doyle Jr. (BSAE '65, MSAE '67)
Robert K. Selke (MSESc '68)
Keith W. Huiatt Jr. (BSAE '69)

1970s

Stephen K. Schwaiger (BSAAE '72)
Duane Ernest Wolting (BSAAE '72)
James E. Gutknecht (BSAAE '73)

1980s

James E. Robinson (BSAAE '81)
Andrew C. Boner (BSAAE '84)
Douglas Michael Olander (BSAAE '86)

1990s

Mark J. Snauffer (MSAAE '90)

2000s

Brian Tyler Renstrom (BSAAE '05)
Daniel Patrick Uffelman (BSAAE '06, MSAAE '08)



Col. Charles C. "Charlie" Bock, Jr. (1925-2019)

Col. Charles C. "Charlie" Bock Jr., who piloted the first flight of the B-1 bomber as a chief test pilot, died Aug. 22, 2019. He was 93.

Bock (BSAE '49, OAE '16) served in the Air Force for 30 years as a bomber pilot, fighter pilot, test pilot and a military astronaut designee. He retired from the Air Force in 1973 to take a position with Rockwell International Corporation as chief test pilot for the B-1 bomber program. In 1974, Bock piloted the first flight of the bomber. He was responsible for all aircrew training and had a major influence on the formulation of the B-1 flight test program priorities and objectives.

Bock flew 105 different types of aircraft and booked 10,000 flying hours, according to the Iowa Flying Museum. He earned multiple awards for his service, including earned two Distinguished Flying Crosses and six Air Medals and the Legion of Honor.

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