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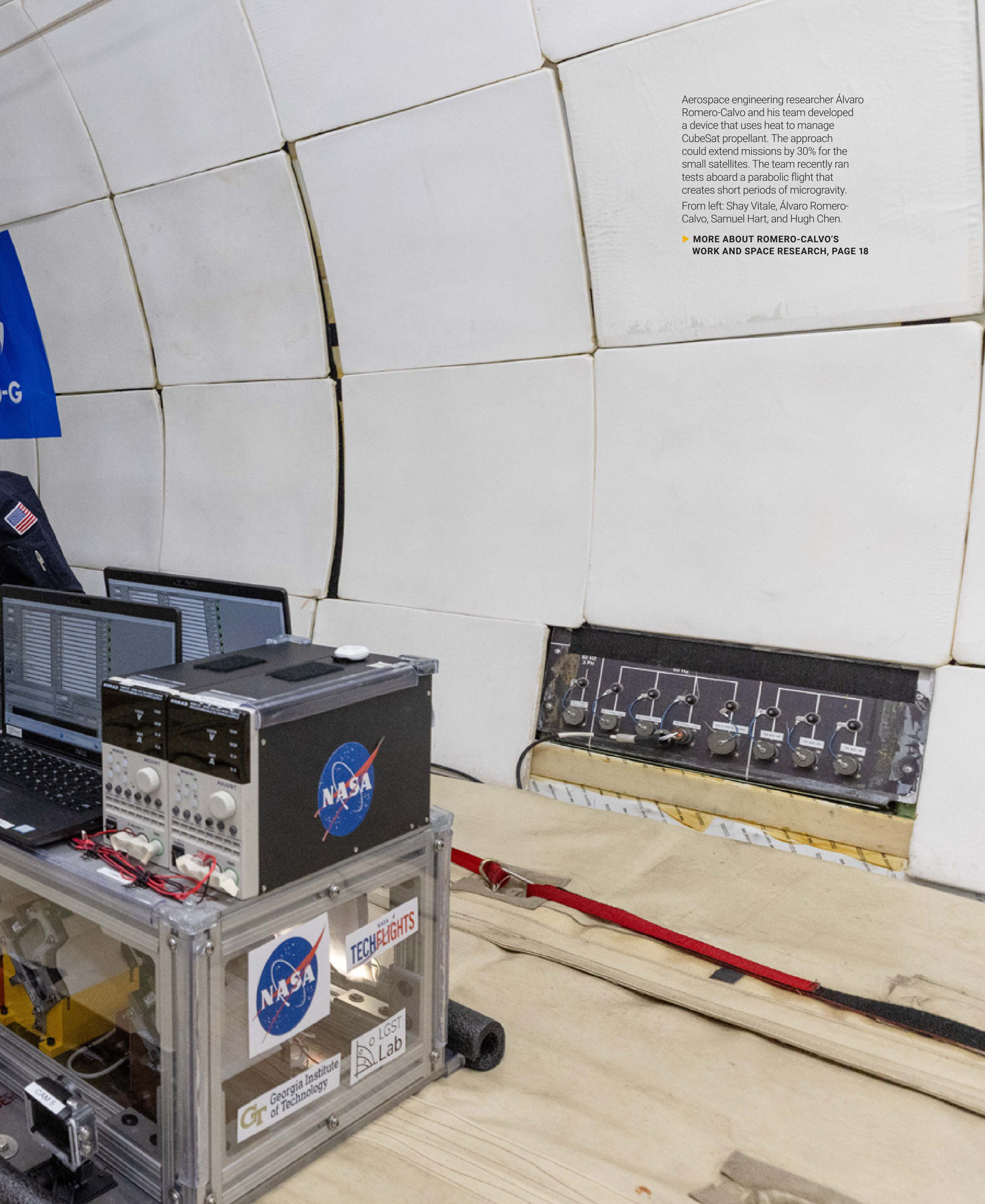
SPRING 2025

GEORGIA TECH COLLEGE OF ENGINEERING

the AEROSPACE issue

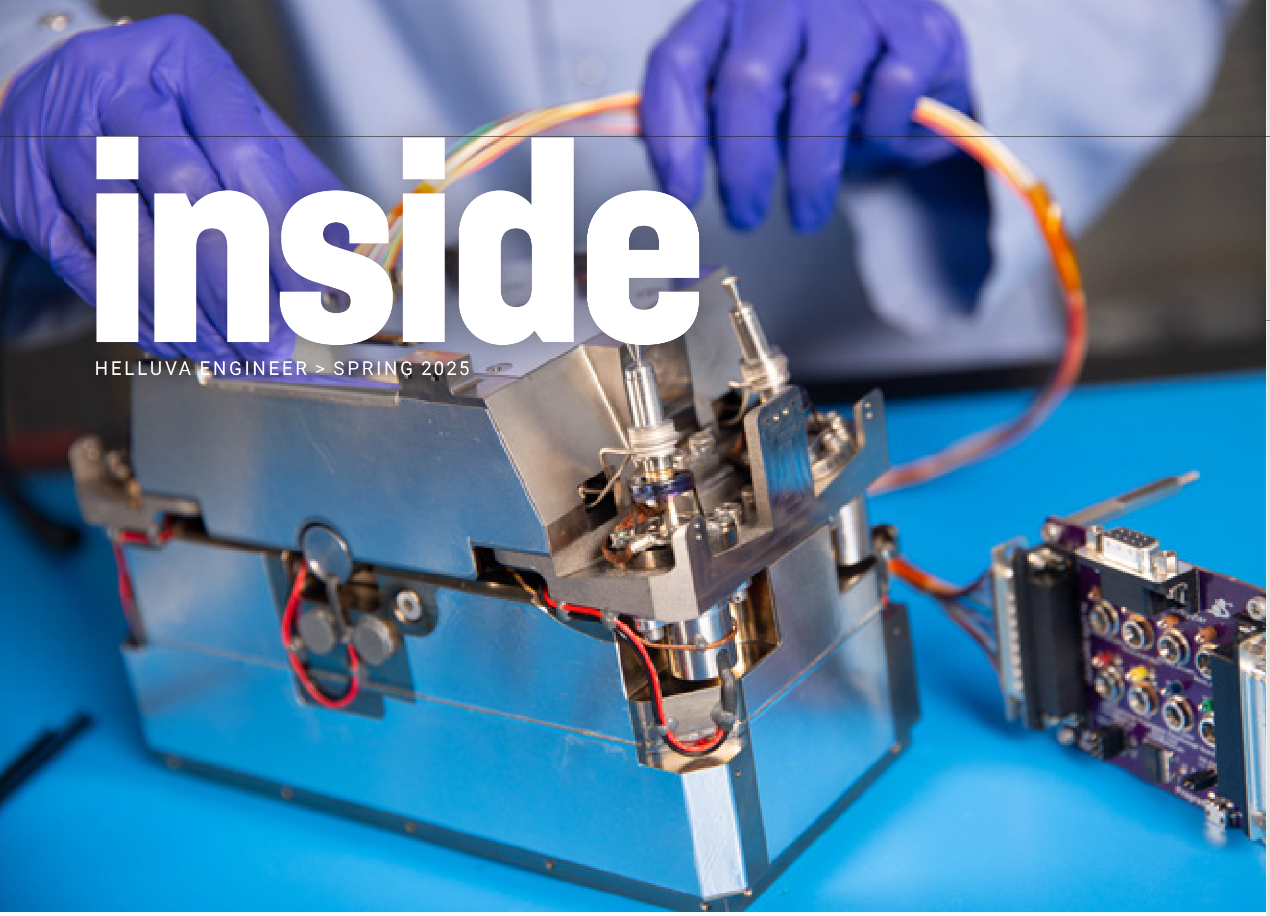
STEVE BOXALL



Aerospace engineering researcher Álvaro Romero-Calvo and his team developed a device that uses heat to manage CubeSat propellant. The approach could extend missions by 30% for the small satellites. The team recently ran tests aboard a parabolic flight that creates short periods of microgravity.

From left: Shay Vitale, Álvaro Romero-Calvo, Samuel Hart, and Hugh Chen.

▶ **MORE ABOUT ROMERO-CALVO'S WORK AND SPACE RESEARCH, PAGE 18**



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HELLUVA ENGINEER > SPRING 2025

FEATURES

WE ARE

Above: The propulsion system of Lunar Flashlight, one of many CubeSats launched from Georgia Tech's small spacecraft pipeline, page 18.

HELLUVA ENGINEER
GEORGIA TECH COLLEGE OF ENGINEERING MAGAZINE SPRING 2025

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Dear Friends,

I never played football as a kid, but I watch enough of the sport to know that timing is everything. Quarterbacks don't throw to their wide receivers; they throw in front of them. By aiming where the receiver is going — rather than where they are — quarterbacks make sure the ball arrives in the right spot at the right time.

We use the same playbook in the College. Part of what makes us successful is not focusing on where we are, but looking ahead. We anticipate the trends and technologies on the horizon, then hire researchers thinking about them so that we're on the ground floor of the future. They teach our students about these possibilities, leading them toward careers where they will implement these ideas of tomorrow.

Aerospace engineering is a great example of this strategy. We recognized about a dozen years ago that briefcase-sized CubeSats were emerging as an ideal (and cheaper) way to explore low earth orbit. We didn't have many researchers with this expertise, so we hired Brian Gunter and Glenn Lightsey. They've built a small satellite pipeline and put a half dozen projects in orbit. More than a dozen will launch in the next few years.

Similarly, with private companies sending rovers to the moon, we've added Yashwanth Nakka to our AE faculty. He isn't thinking about a single machine. He specializes in algorithms that will allow multiple rovers to work as a team on the lunar surface. Closer to home, flying taxis may someday ferry people into and around urban areas. We're designing those vehicles, and we're already thinking about their effects on neighborhoods that will be close to where they take off and land.

We're doing all of this in a state where the aerospace industry is a priority. Aerospace products are Georgia's top export, generating $12.6 billion in 2024. Companies like Lockheed Martin, Honeywell, and Delta (which celebrates its 100th anniversary this year), are among those at the center of the industry, and we are proud to partner with each of them to shape the future.

Our Daniel Guggenheim School of Aerospace Engineering will celebrate its own centennial in six years. But, again, we're already looking ahead. One of the College's top priorities is to mark the School's first century with a new building for the nation's top-ranked public aerospace program.

In these pages, you'll learn more of what we're doing in aerospace, from plane designs and drones to satellites and planetary exploration. As usual, the work is spread throughout the College and extends into our alumni network.

They say the sky is the limit. I say that it's limitless. And we're pushing the boundaries every day.

Sincerely,

Raheem Beyah
Dean and Southern Company Chair

CANDLER HOBBS

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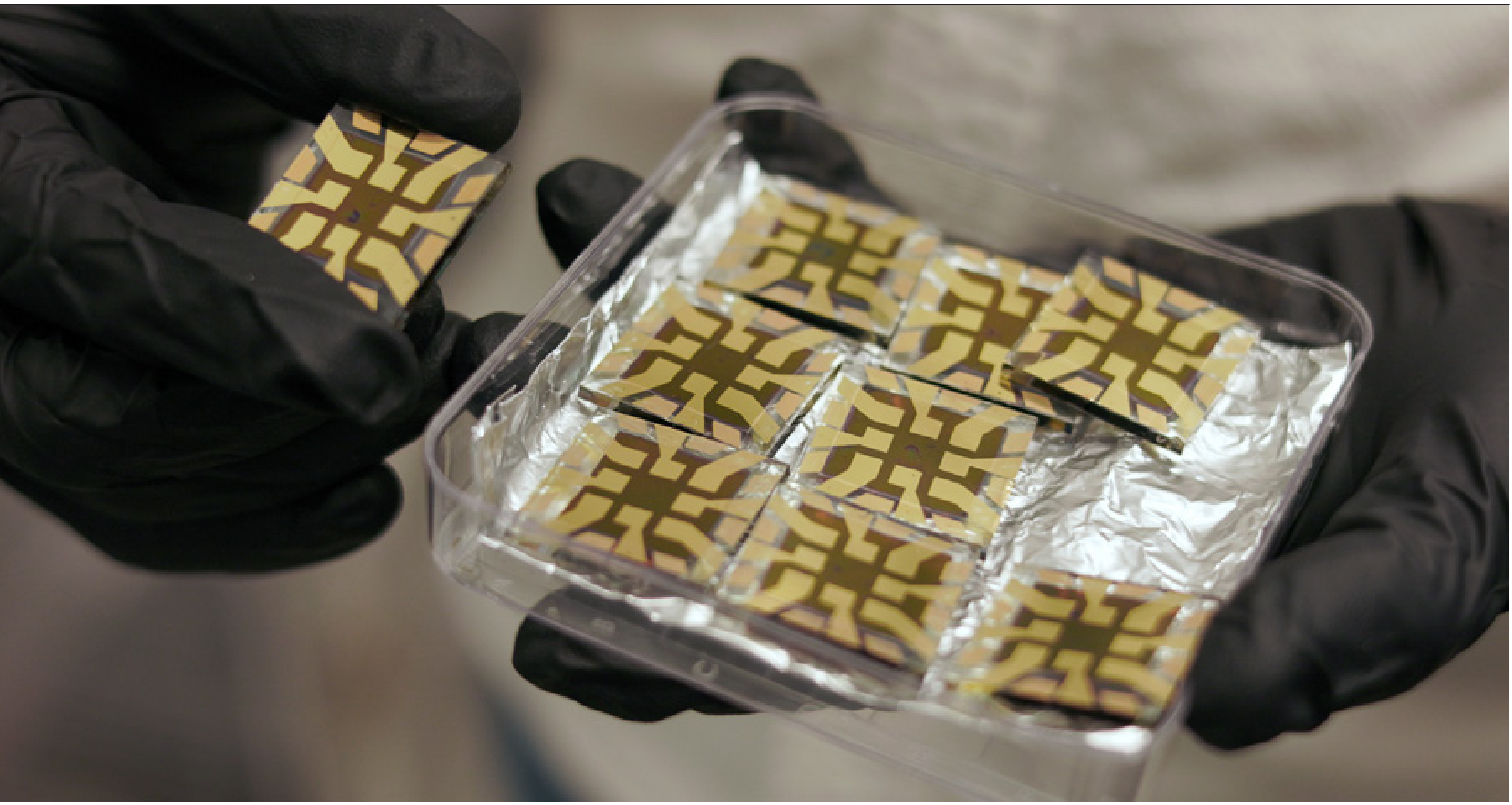
in the field



Researchers Build Stable Solar Panels Without Silicon

Materials engineers are developing a new, easily produced domestic material that could help increase solar cell production in the U.S. and do it more cheaply.

For years, Juan-Pablo Correa-Baena's research group in the School of Materials Science and Engineering has explored using perovskite crystals as an alternative to silicon. Silicon requires significant energy to produce and process. Perovskite is made of iodine atoms, lead, and organic elements. It's a prevalent replacement and is just as efficient as silicon at producing power.

However, perovskite has one major drawback: Compared to silicon's 20 years of use, perovskite-made cells deteriorate after a year. The material is especially sensitive to hot summer temperatures and can decompose before the solar panel can help a homeowner save on energy costs.

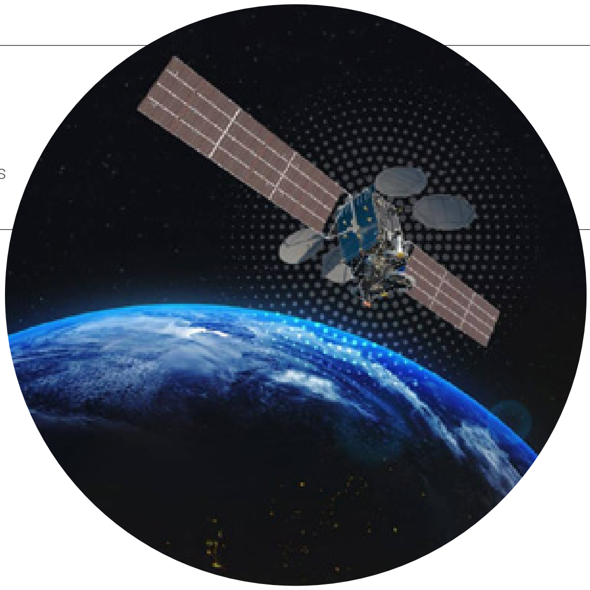
Correa-Baena's lab has found a way to stabilize perovskite solar cells. The cells have one positive and one negative electrode, like a battery, with the perovskite cell sandwiched between them. Before placing a positive electrode at the top of the cell, the researchers infuse a bit of titanium into the top layer.

"We've made one of the layers that causes the longevity issue more robust and resilient to especially high temperatures," Correa-Baena said. "By inserting titanium, we can prevent the degradation process, and then we can test the solar cell on roofs or anywhere."

▶ TESS MALONE

Infusing perovskite solar cells with titanium stabilizes the material and increases its longevity, creating a competitive and compelling alternative to silicon.

CHRISTOPHER MCKENNEY



A rendering of Intelsat's Galaxy 37/Horizons-4 communications satellite.

ECE, Intelsat Preparing Future Satellite Communications Leaders

The School of Electrical and Computer Engineering (ECE) has joined forces with Intelsat to improve industry access for students and strengthen the School's satellite communications curriculum.

Intelsat operates one of the world's largest integrated satellite and terrestrial networks, providing secure and reliable connectivity to governments, businesses, and communities across the globe.

"This collaboration is a significant step in providing our students with cutting-edge knowledge and hands-on experience in a field that is crucial for global connectivity and technological advancement," said Arijit Raychowdhury, Steve W. Chaddick School Chair of ECE and professor.

Intelsat is helping the School establish new content and courses in satellite communications, hardware, and space mission design. The goal is to make ECE one of the deepest, most compelling space technology and engineering programs in the country.

"Georgia Tech is renowned for its innovative approach to engineering education and research," said Carmel Ortiz, senior vice president of technology and innovation at Intelsat and a Georgia Tech alumna. "This collaboration allows us to contribute to the development of future leaders in satellite communications, ensuring that the next generation is well-equipped to tackle the challenges of an increasingly connected world."

▶ **DAN WATSON**

Alumnus Tim Lieuwen Named Tech's EVP for Research

Timothy Lieuwen is Georgia Tech's new executive vice president for Research, a role responsible for leading Tech's $1.37 billion research enterprise.

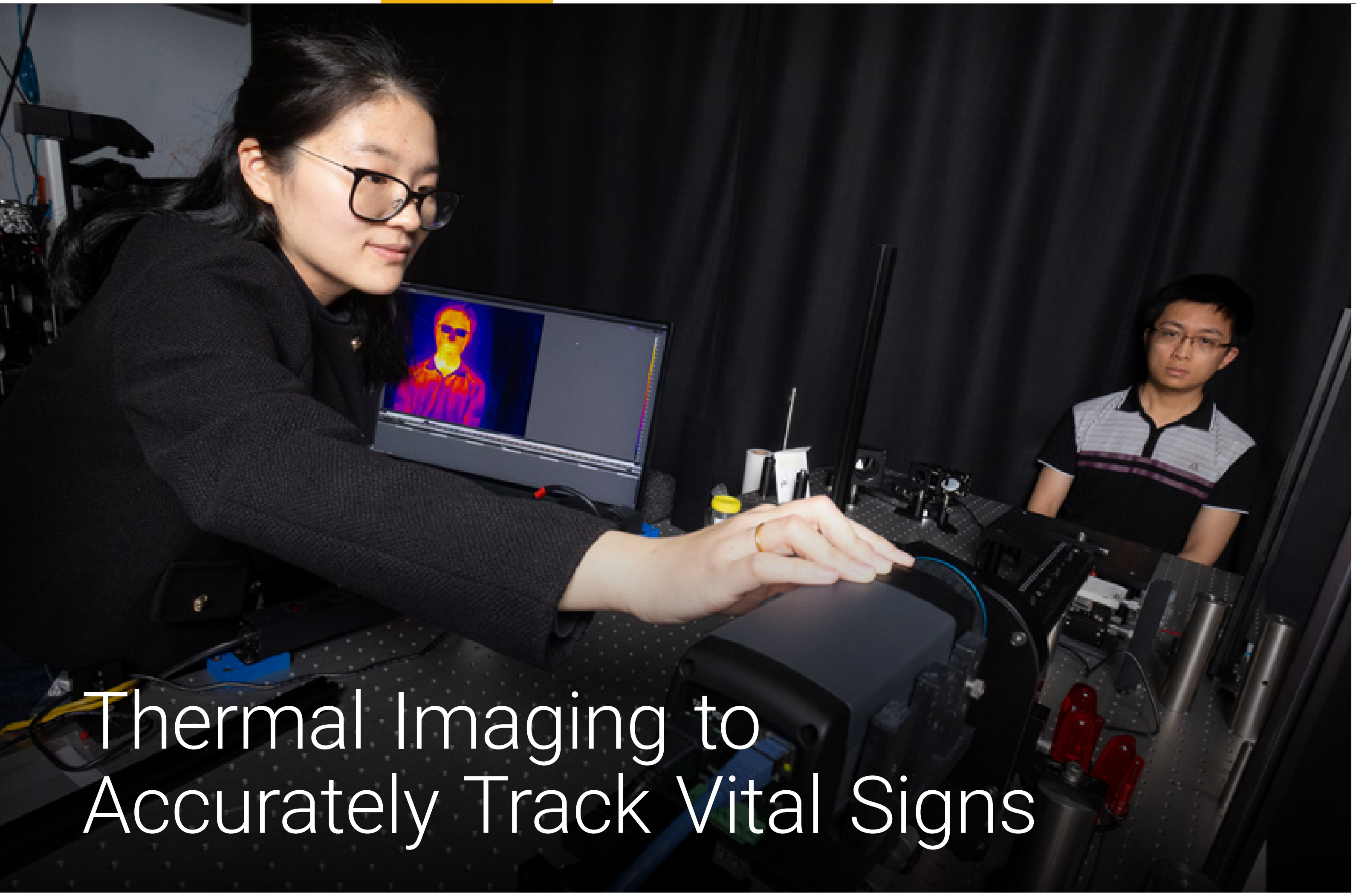
Lieuwen earned his master's and Ph.D. in mechanical engineering at Tech and has spent more than 25 years on the faculty of the Daniel Guggenheim School of Aerospace Engineering, where he is a Regents' Professor and the David S. Lewis, Jr. Chair. He also served as executive director of the Georgia Tech Strategic Energy Institute for 12 years.

"I am honored to step into this role at a time when research and innovation have never been more critical," Lieuwen said. "Georgia Tech's research enterprise is built on collaboration — across disciplines, across industries, and across communities. Our strength lies not just in the breakthroughs we achieve, but in how we translate them into real-world impact."

Lieuwen's own research spans energy, propulsion, energy policy, and national security. He has worked closely with industry and government to develop new knowledge and see its implementation beyond the lab.

▶ **SHELLEY WUNDER-SMITH**

LIEUWEN: CHRISTOPHER MCKENNEY; SATELLITE: INTELSAT



Thermal Imaging to Accurately Track Vital Signs

Top: Postdoctoral scholar Dingding Han adjusts a thermal camera capturing an image of Ph.D. student Corey Zheng.

Above: Additional detail and contours of temperature and shirt material in a processed phasor thermographic image.

Biomedical engineers have developed a system for collecting and processing thermal images that allows for reliable, detailed measurement of vital signs such as respiration and heart rate or body temperature.

Their monitoring approach is passive and requires no contact. The system could one day lead to early detection of cancer or other diseases by flagging subtle changes in body tissues.

The researchers have overcome the spectral ambiguity inherent in conventional thermal imaging, sharpening the texture and detail they can extract from images and removing the effects of heat from the environment surrounding a subject.

In their study, the researchers showed they were able to precisely measure heart rate, respiration rate, and body temperature from multiple parts of the body. The tool effectively differentiated vital signs in scenes with multiple people. It also accurately captured variations in respiration rate before and after exercise.

The system uses common equipment, making it powerfully adaptable and easy to integrate into virtually any thermal imaging platform.

"This could be a cornerstone for future broad biomedical diagnosis," said Dingding Han, lead author on the study and a postdoctoral scholar in the George W. Woodruff School of Mechanical Engineering. "With this phasor thermographic technology, we can enhance the accuracy and efficiency of thermal imaging to detect abnormalities. The technique has the capability of getting material segmentation, which is not possible with only pure thermal imaging."

What drives the improvement in Han's system is its ability to eliminate the "fuzziness" of typical thermal images. Usually, they don't sharply differentiate between subtle temperature variations, and heat in the environment can make the images too noisy for precise measurement of physiological signals.

JOSHUA STEWART

CANDLER HOBBS

Dupuis Receives Japan Prize

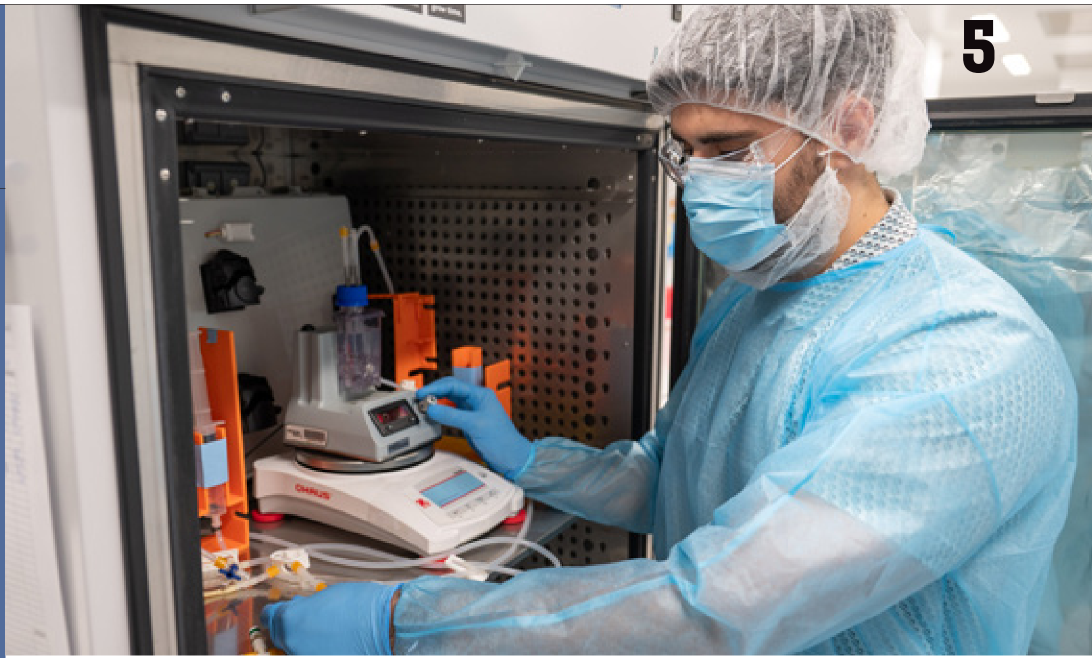
Electrical and computer engineering Professor Emeritus Russell Dupuis has been recognized with the Japan Prize for laying the foundation for LEDs, solar cells, lasers, and other modern technology.

The award is one of a few international awards regarded among scientists as second only to the Nobel Prize. It honors manufacturing techniques Dupuis first demonstrated nearly 50 years ago that have made it possible to mass produce and commercialize compound semiconductors.

The Japan Prize Foundation described Dupuis' work as "the foundation upon which our modern information society is built." Compound semiconductors are found in smartphones, LED light bulbs, barcode scanners, and many other devices.

▶ JOSHUA STEWART

DUPUIS: PETE WINKEL; CELL LAB: ROB FELT



A $40M Boost for Cell Manufacturing

A $20 million investment from the Marcus Foundation aims to make high-quality, lifesaving cell therapies more affordable, reliable, and accessible than ever before.

Part of an overall $40 million Georgia Tech initiative, the award is among the final gifts personally directed by philanthropist, entrepreneur, and The Home Depot cofounder Bernie Marcus.

"His challenge to Georgia Tech was clear," President Ángel Cabrera said. "Use our engineering expertise to make cell therapies more accessible and cost-effective and develop cures for incurable diseases. This generous award is a testament to our shared belief in the power of innovation and technology to improve lives, and it's an honor for Georgia Tech to fulfill Bernie's vision for the future of healthcare."

The funding will ignite innovation at Georgia Tech's Marcus Center of Excellence for Cell Biomanufacturing, formerly the Marcus Center for Therapeutic Cell Characterization and Manufacturing. The Center has been bioengineering potential cellular cures for more than seven years.

Now Tech engineers will advance work at the center and within the National Science Foundation-funded Engineering Research Center in Cell Manufacturing Technologies (CMaT) to develop automated bioreactor systems that eliminate the need for costly cleanrooms.

Marcus and CMaT Director Johnna Temenoff compared the current state of cell therapies to the early days of the automobile industry. She said this infusion of funds will allow her team to shift from handcrafted production to an assembly-line approach.

"I firmly believe that for us to make good on the promises of these biotechnologies to improve healthcare worldwide, we must be able to manufacture them in a more reproducible and cost-effective manner," said Temenoff, Carol Ann and David D. Flanagan Professor of biomedical engineering. "Georgia Tech's distinctive strength lies in our engineering expertise, allowing us to tackle difficult biological problems."

The award has the potential to significantly boost Georgia's bioeconomy, making the state a hub for advanced therapy development and biomanufacturing. It also will attract jobs and top-tier talent to the region.

▶ SHELLEY WUNDER-SMITH

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3D Printed — and It Sounds Amazing

A love for engineering and a lifelong passion for music led mechanical engineering graduate student Kevin Kamperman to an unusual project: 3D printing a fully functioning acoustic violin.

And what started as a final project in an additive manufacturing class now is a provisionally patented design.

"Seeing this dream become a reality is deeply fulfilling," said Kamperman, a multi-instrumentalist himself. "This invention has the potential not only to be practical but also to bring joy to those who might one day use it to create music. Knowing that something I contributed to could inspire creativity in others is incredibly rewarding."

The intent of the violin design was to replicate both the sound and feel of a traditional wooden instrument using only additive manufacturing materials and methods. Kamperman and his teammates worked with Endeavor 3D in Douglasville, Georgia, to fabricate their design using the company's advanced, powder-based 3D-printing equipment.

Once the group made a prototype, they collected performance data in an anechoic chamber at the Georgia Tech Research Institute, comparing their violin to a mid-priced and a high-priced wooden instrument.

In their tests, the sound from the polymer violin ranked highest for warmth, natality, and brilliance. Test violinists praised the warmth of the D and G strings but described the A and upper E strings as slightly nasal and less brilliant. A loudness test revealed the polymer violin produced slightly quieter sound than its wooden counterparts.

Kamperman said he's excited about making music and arts more accessible, affordable, and inclusive. He hopes combining the precision of 3D printing with the artistry of instrument-making can break down barriers for musicians and revolutionize traditional craftsmanship.

▶ MIKEY FULLER

VIOLIN: KEVIN KAMPERMAN; AIR TESTING SITE COURTESY: HAROULA BALIAKA

LA Fires Trigger Temporary Spike in Airborne Lead

When the Los Angeles wildfires quickly spread in January, Georgia Tech scientists and their collaborators observed a 110-fold jump in airborne lead levels for several days.

It's the first real-time data on airborne lead, and it's thanks to an air quality measurement network led by Georgia Tech's Sally Ng. The project is funded by the National Science Foundation and operates at 12 sites across the U.S.

The network measured tiny particles smaller than 2.5 micrometers in diameter (PM2.5) — small enough to enter the lungs and bloodstream. Unlike typical wildfires that burn natural materials such as grass and trees, the Eaton Canyon and Palisades fires burned through infrastructure and homes, including painted surfaces, pipes, vehicles, plastics, and electronic equipment.

Many of the destroyed buildings were constructed before 1978, when lead paint was commonly used.

"Our work has provided us with new insights into the air we breathe, with unprecedented levels of detail and time resolution," said Ng, Love Family Professor of Chemical and Biomolecular Engineering and the network's principal investigator. "Beyond the mass concentration of PM2.5 that is typically measured, we are now able to detect a wide range of chemical components in the aerosols in real time to better understand and evaluate to what extent one is exposed to harmful pollutants."

Lead poses significant health risks, particularly for children. While chronic lead exposure is well-documented, the effects of short-term spikes, like those recorded during these fires, are less understood.

▶ ANGELA BARAJAS PRENDIVILLE

An air monitoring station in the L.A. area.

Alumni Awards Honor Engineers Making an Impact

Engineering Hall of Famers, from left: Jim Borders, Marshall Wingo, Robyn Gatens, Ron Nash, José Domingo Pérez, and Carl Ring.

Their influence shows in Atlanta's Midtown skyline, the software millions of Americans use to prepare their taxes, and in low earth orbit aboard the International Space Station. They are entrepreneurs and doctors, pro sports executives, and investors.

They're also a group of 29 Georgia Tech graduates honored at the 2025 College of Engineering Alumni Awards Induction Ceremony.

In addition to the individual honorees, Dean Raheem Beyah presented two special awards. The Dean's Appreciation Award went to the Wallace H. Coulter Foundation, whose landmark investment set the stage for the College's joint biomedical engineering department with Emory University.

The Dean's Impact Award went to SlateSafety founders Zachary Braun, Joseph Boettcher, and Tyler Sisk for their innovative approach to protecting workers. Their flagship wearable device monitors heat stress, environmental conditions, and real-time location to help avoid some of the 300 million worker injuries reported worldwide every year.

▶ JOSHUA STEWART

CAROLINE JOE

ENGINEERING HALL OF FAME
- James R. Borders (ME 1983)
- Sheldon J. Fox (EE 1981, M.S. EE 1982)
- Robyn Gatens (CHE 1985)
- Charles H. Gaylord, Jr. (AE 1967, M.S. AE 1969)
- H. Ronald Nash, Jr. (IE 1970)
- José Domingo Pérez (CE 1971)
- Carl D. Ring (ME 1978)
- Marshall D. Wingo (TEXT 1967)

THE ACADEMY OF DISTINGUISHED ENGINEERING ALUMNI
- Latanza W. Adjei (IE 1998)
- Clint Bailey (TE 1997)
- Geraldine Ekpo (BME 2004)
- Ken Klaer (IE 1981)
- Roderick McLean (M.S. EE 1993)
- Guillermo A. Ruiz II (CHE 1998)
- John Slaughter (EE 1989, M.S. EE 1990)
- Lindsey Thornhill (ME 1984, M.S. ME 1986, Ph.D. ME 1996)
- Gary Weissel (AE 1993)
- H. Arthur "Art" Williams (CE 1983)

THE COUNCIL OF OUTSTANDING YOUNG ENGINEERING ALUMNI
- Nathan Buchbinder (MBID 2016)
- Shreya Dwarakanath (MBA 2019, M.S. MSE 2019, Ph.D. MSE 2020)
- Raghav Kohli (EE 2007)
- Jacob M. Kwasnik (AE 2008)
- Alexandra Mandrycky (IE 2013)
- Robert D. Moser (CE 2007, M.S. CE 2009, Ph.D. CE 2011)
- Anna Thomas (CHBE 2013)
- Emily Woods (ME 2010)

DEAN'S APPRECIATION AWARD
The Wallace H. Coulter Foundation

DEAN'S IMPACT AWARD
SlateSafety
- Joseph Boettcher (EE 2017, M.S. CS 2021)
- Zachary Braun (CMPE 2017, M.S. CS 2021)
- Tyler Sisk (EE 2017)

Engineering 21st Century Flight

THE NEW IDEAS AND EMERGING DESIGNS THAT WILL CARRY US (AND OUR CARGO) SAFELY INTO THE SKY WILL BE MORE SUSTAINABLE ENVIRONMENTALLY AND ECONOMICALLY THANKS TO THE WORK OF GEORGIA TECH ENGINEERS.

BY JOSHUA STEWART

9

When a military helicopter and a passenger jet fatally collided over the Potomac River in Washington D.C. earlier this year, the tragedy illustrated a stark truth: Our skies are crowded. And they're only getting more so.

When the international trade group for airlines committed in 2021 to "fly net-zero by 2050," the pledge underlined a growing problem: Aviation already accounts for 3% of global carbon emissions. That's going to balloon if passenger miles double by 2050, as expected.

When journalists produce a steady stream of headlines about autonomous air taxis, the implication is clear: New electrically powered vertical takeoff and landing (eVTOL) aircraft suggest flying could look wildly different in some corners.

On the front lines of each of those issues — and more — you'll find Georgia Tech engineers doing the critical research to smooth out the turbulence of a dynamic and changing industry. From designs that move beyond the tube-and-wing flying the skies today to new ways to model passenger demand and offer new kinds of travel packages, Yellow Jacket fingerprints are everywhere.

"Many of these things that are happening [in aviation] have roots directly here," said aerospace engineer and Regents' Professor Dimitri Mavris.

So grab a boarding pass, adjust your seat back, and see how engineers are planning, modeling, designing, and building the future of flight.

One of Georgia Tech's collaborations with NASA is called ATH2ENA — the aircraft body design merges a traditional tube-and-wing with a blended wing in a concept for a future airliner.

Meet the RAVEN

In an ordinary-looking hangar a few miles northwest of campus, the bones of a new kind of aircraft are taking shape. The steel frame won't ever get seats or an aluminum skin — or actually fly, for that matter. But it's a key stage in building a flying laboratory that will help NASA and Georgia Tech engineers research and test the technologies needed to develop eVTOL aircraft.

Eventually, the finished vehicle — called RAVEN — will look similar to the small general aviation planes common at executive and regional airports. But it will be entirely electric, autonomously piloted, and capable of helicopter-like vertical flight and hover with plane-like forward flight.

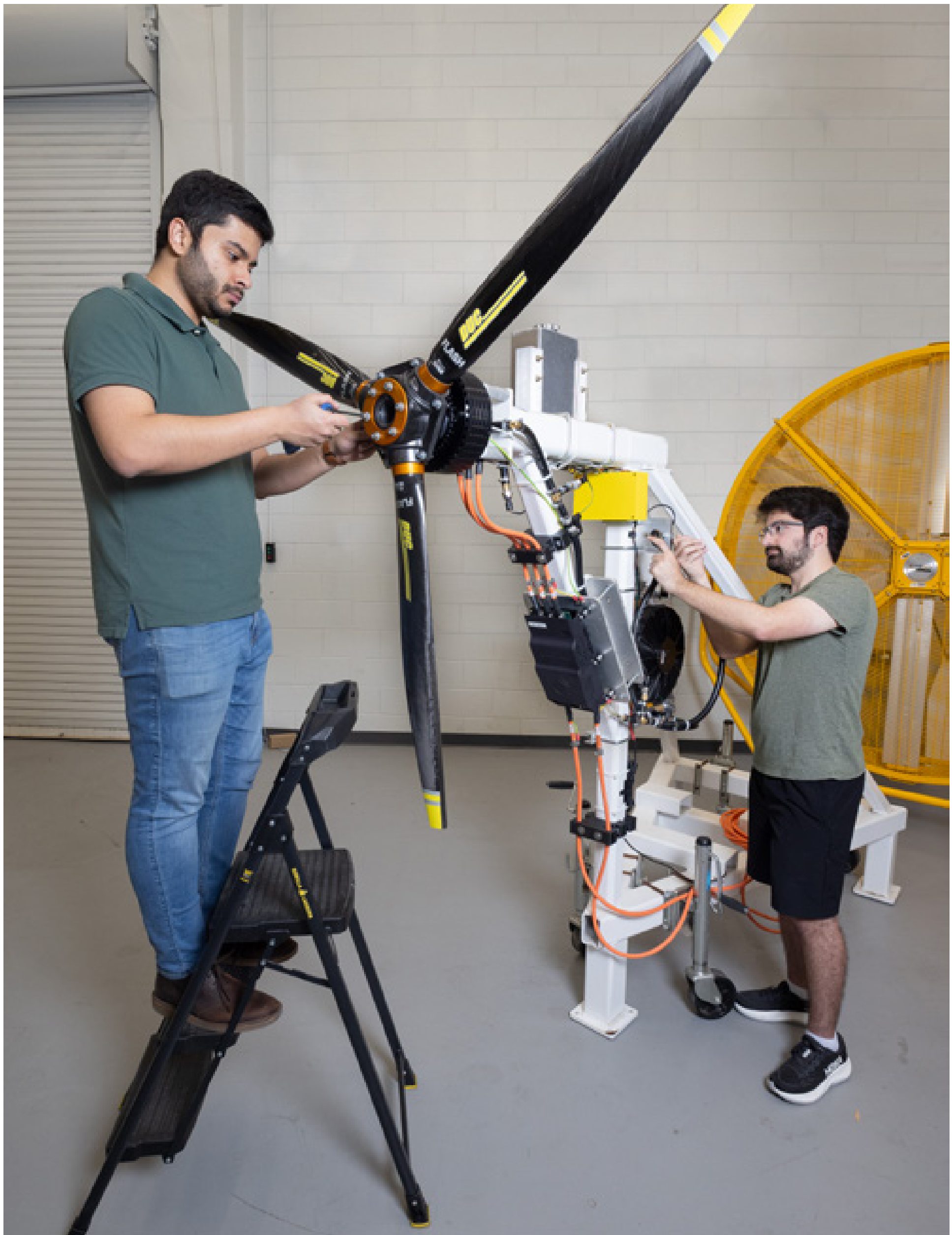
To speed development and keep costs low, the aircraft is based on the Bede BD-6, an experimental fixed-wing plane commercially available as a home-built kit. It will have four tilting rotors able to pivot from vertical lift and hovering to forward movement plus two additional static rotors to aid in vertical flight. Each of those six-foot-diameter rotors will be powered by its own 40-kilowatt electric motor — equivalent to about 50 horsepower each.

At 1,000 pounds, the RAVEN — Research Aircraft for eVTOL Enabling Technologies — is about 1/5 the size of the kinds of autonomous vehicles that could someday fly people and cargo. The large size is perfect to offer real insight into systems and designs for those future aircraft.

"At this weight, you're a lot more relevant than a typical 20- or 50-pound research aircraft. The physics don't scale in the same way. You need to be closer in size to the larger aircraft to get relevant results," said Brian German, professor in the Daniel Guggenheim School of Aerospace Engineering (AE). "We want to be able to publish flight data that's relevant and carry relevant research payloads to collect information about the aerodynamics, acoustics, electric propulsion system, and more."

German approached NASA a few years ago with the idea of building this kind of dedicated research platform at Tech that also would give students hands-on experience with experimental aircraft design and flight. The first steps of that journey will travel just a few hundred feet this summer, when German and his team roll the steel frame "iron bird" out to a closed runway to test everything. With cable runs, electric motors, and propellers laid out just like the airplane, it's an important milestone to eventually realizing the actual RAVEN.

"We'll run it up and take a lot of data," German said. "Can we produce the power and thrust levels we needed? Do we have any electromagnetic interference? That's a big deal. We have a high-voltage, high-power electrical system — does that interfere with the low-voltage command and control signals that control everything? Do any of the components overheat? Those are the kinds of things we'll be looking at."



> "My vision is for Georgia Tech to have an ecosystem around research and flight testing for advanced air mobility. ... Our work will become a major enabler of bringing businesses and an advanced air mobility workforce to Georgia."
>
> Brian German

Meanwhile, a new hangar facility rising in Georgia Tech's North Avenue Research Area will offer new space for testing and development of the RAVEN's systems. The Aircraft Prototyping Laboratory (APL) also will house an electric powertrain lab, a propulsion system test cell, an avionics lab, and composite fabrication areas. Scheduled to open in fall 2025, the APL will complement the off-campus airport hangar where the RAVEN's iron bird is coming together, German said.

"My vision is for Georgia Tech to have an ecosystem around research and flight testing for advanced air mobility," he said. "The end state is flight testing, but the other aspects are also super interesting — our graduates will have a rich set of experiences that make them even more valuable to the industry and our work will become a major enabler of bringing businesses and an advanced air mobility workforce to Georgia."

Windy Cities

If eVTOL vehicles are coming to skies near you, there's much to do beyond designing the vehicles themselves. A signature research effort looking at the broader picture has been housed at Georgia Tech for more than 40 years.

The Vertical Lift Research Center of Excellence focuses on all areas of vertical lift: traditional helicopters and other rotorcraft, urban air mobility vehicles and drones, and even rotorcraft that could one day help us explore other planets and moons.

Led by Marilyn Smith, the Center operates on a five-year cycle with funding from NASA, the U.S. Army, and the U.S. Navy. Three years into the current cycle, $16 million worth of research is underway on a dozen projects involving 10 faculty members and six universities. The Center also has become a hub for training — one of the few places in the country with a full scope of curriculum for rotorcraft engineers.

Smith is a respected scholar in aerodynamics and aeroelasticity, studying the interactions of air and aircraft structures. And for a long time, she's pushed for more study of those interactions in the congested urban areas where advanced air mobility flights would operate.

"When advanced air mobility vehicles are performing terminal area operations — taking off and landing — they will not be above the building line where we typically fly aircraft. You're not in a nice, open airport area," said Smith, the David S. Lewis Professor in AE. "A significant issue is that the vehicles will encounter many transients with the wind: There's a lot of turbulence as the wind moves around buildings and other structures, and there will be vortices that you have to fly through. That's a considerable safety issue, especially during takeoff or landing."

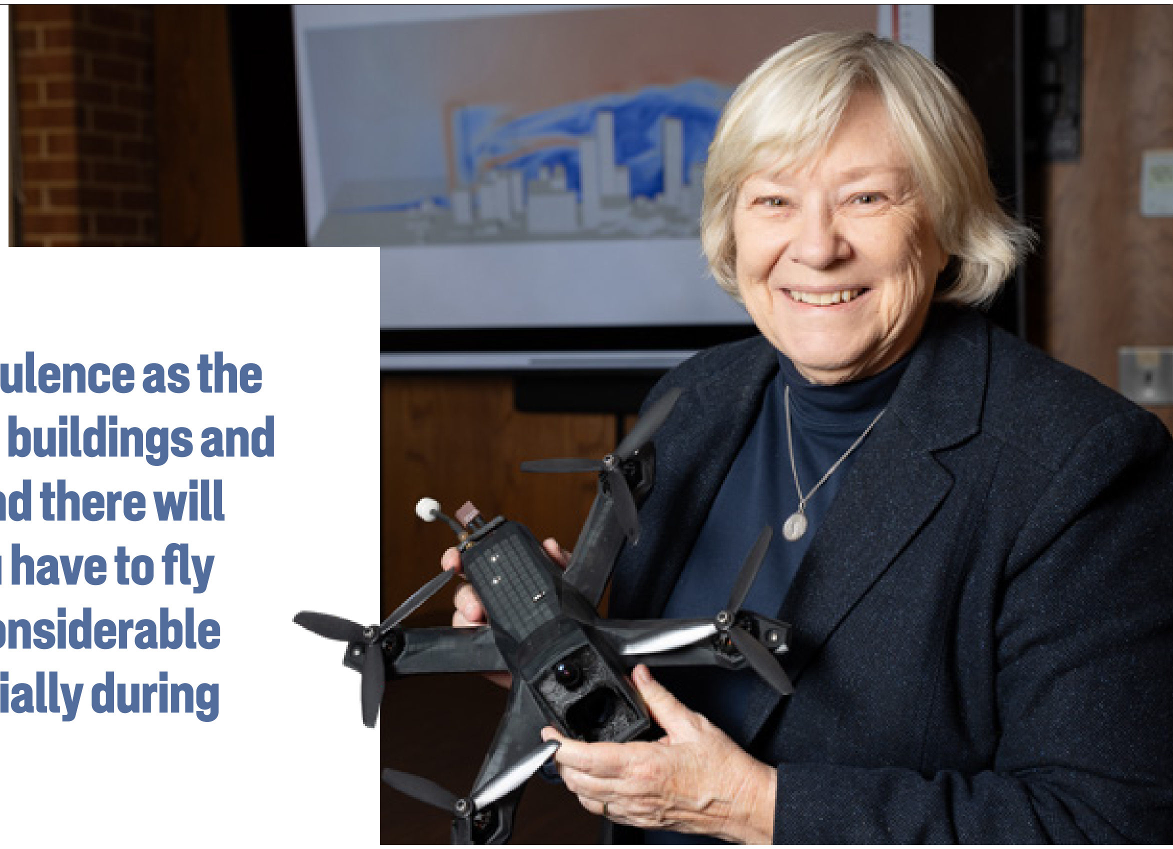
Smith said pilots and aircraft will need to be able to predict and adapt to these conditions. That means designing aircraft for a significantly different flying environment and training pilots for the conditions. It also means establishing operational parameters — Can we fly in today's conditions? What routes and trajectories are safest?

OPPOSITE PAGE
Top: applying a rust remover to prepare the RAVEN iron bird for painting. Bottom: Maxwell Kramer, a master's student in Brian German's lab, and research engineer Ayusha Jha work on one of the RAVEN's electric motors and a propeller ahead of ground tests.
THIS PAGE
A conceptual rendering of the RAVEN in flight.

WHAT IS ADVANCED AIR MOBILITY?

The phrase refers to a range of emerging aviation technologies and new aircraft designs to move people and goods. It's an umbrella term that can include autonomous or human-piloted eVTOL craft used for short trips, drones, and more. In urban areas, these kinds of innovations can be more specifically called "urban air mobility" or "regional air mobility."

OPPOSITE PAGE: CANDLER HOBBS; RENDERING: NASA



CANDLER HOBBS

> **"There's a lot of turbulence as the wind moves around buildings and other structures, and there will be vortices that you have to fly through. That's a considerable safety issue, especially during takeoff or landing."**
>
> Marilyn Smith

To that end, Smith and her team have developed tools and models for the last few years that would predict conditions where nonlinear flight would occur, particularly in what's known as the "roughness sublayer" of air — building heights plus 50%. Smith is working with a company that develops industry-standard models and simulations to incorporate her group's work into flight simulators.

It's potentially life-and-death work if air taxis and drones are to become viable operators.

"Are you designing the vehicle so that it can be the most productive flying through these areas? You don't want conditions to draw too heavily on the battery so that your battery drains too fast," Smith said. "If you're flying a lighter drone, can you actually fly it on that path that day, or is it going to get slammed into the side of a building because it's just too windy?"

In a related project for NASA — especially timely after this winter's raging wildfires in California — Smith is modeling the environment around wildfires and fires in urban areas. Her models predict the direction of spread and thermals generated by the intense heat to offer insights on potential impacts and ideal flight paths for drones dropping fire retardants.

Another area of research in Smith's lab looks at what happens when tilt-rotor aircraft like the RAVEN transition from hover to forward flight.

"We don't have good databases for solver validation and to understand the physics for tilt-rotor conversions," Smith said. "[AE Assistant Professor] Juergen Rauleder is performing extensive experiments on that topic, and we are studying the aerodynamic interactions with him. We're also making sure we can capture the important physics with the simulation tools we have and develop best practices to capture the physics."

Smith said the world of advanced air mobility has shifted from feasibility to the just-as-complex questions of operations, which is why her group's work is crucial.

"People weren't thinking about this before, because they were focused on so many other things: Can you build vehicles? Are they practical?" she said. "At this point we're saying, 'We can build vehicles. They're practical. Now, how do we operate them safely? What are these other problems that we need to solve?'"

The View from 30,000 Feet

The question of safe and efficient operations for advanced air mobility services like cargo flights or air taxis is one of the topics that occupies attention in the Aerospace Systems Design Lab (ASDL). The lab works on advances in civil aeronautics, challenges in air transportation, environmental assessments, and guiding international aviation organizations in setting long-term goals for the industry.

It's a holistic approach to complex aerospace systems, said ASDL Director Dimitri Mavris. That's partly why the lab's fingerprints, and Georgia Tech's, can be found across many of the ambitious efforts to reimagine aerospace designs. For example:

- NASA's X-59 aircraft designed to demonstrate supersonic flight with a sonic "thump" rather than a sonic boom. The project is assessing ground-level noise in an effort to allow for faster-than-sound flight over land. One of Mavris' former Ph.D. students, Michael Buonanno, was the project's chief engineer. He's currently a Lockheed Martin Fellow.
- Another former ASDL student, Nicholas Borer, now at NASA's Langley Research Center, was deeply involved in developing the X-57 experimental aircraft "Maxwell." The plane's distributed electric propulsion design was to have 14 electric motors and propellers along its wings. Though it never expanded beyond ground testing before running out of time and money, the project resulted in significant advances in batteries and other electric aircraft technology.
- Working with Virginia Tech, the lab established the fundamental analysis of the truss-braced wing concept. The work became the springboard for the X-66, another NASA experimental plane that's focused on one day achieving net-zero aviation emissions. The extra-long, thin wings of the design are stabilized by diagonal struts. Combined with advances in propulsion, materials, and systems architecture innovations, the X-66 could use 30% less fuel and produce fewer emissions than today's best aircraft.

"For many of these configurations, there is a bit of quote-unquote Georgia Tech heritage, if you will, from our lab and from the Guggenheim School of Aerospace Engineering," said Mavris, who is the Boeing Professor of Advanced Aerospace Systems Analysis, Langley Distinguished Professor in Advanced Aerospace Systems Architecture, and Distinguished Regents' Professor in AE.

Mavris' team has been involved in evaluations of another new approach called a blended wing body design with a company called JetZero. With a shorter, wider fuselage that blends into a wing, it's a vastly different profile than traditional tube-and-wing aircraft. But it's a more naturally stable design that's lighter and has less drag, boosting efficiency while eliminating the need for large and complex tail surfaces.

Echoes of the blended wing body show up in one of the lab's newest projects through the NASA Advanced Aircraft Concepts for Environmental Sustainability 2050 program. Called ATH2ENA, the design merges tube-and-wing design with a blended wing in a concept for a future airliner.

The ATH2ENA idea uses a hydrogen-electric propulsion system, which is where it gets its full name: Advanced Technology Hydrogen Electric Novel Aircraft. Its unique shape produces a higher lift-to-drag ratio that makes it more efficient while maximizing cryogenic hydrogen storage and balancing weight.

"In a typical tube-and-wing, the passenger cabin is constrained by placement of the fuel tanks — passengers can feel like they're going through the tank. In this case, the cabin is in the middle of that blended body and the tanks are not on top of the passengers. So, it has some appeal," Mavris said.

»»»»»

Georgia Tech has played a role in many experimental aircraft designs in the quest for safer and more efficient operations in the future.

Renderings, clockwise from top: a blended wing body design from NASA and JetZero, NASA's X-66, and NASA's X-57.

X-57 AND X-66: NASA; BLENDED WING: JETZERO / NASA

The ASDL team was the only university-based group selected for the research program. ATH2ENA is really the endpoint of their work. Researchers will develop a comprehensive assessment of sustainable technologies — alternative fuels, propulsion systems, and aircraft designs. The most promising approaches will inform the ultimate ATH2ENA design and development.

And that gets back to the 30,000-foot view ASDL has over aerospace systems. Yes, their work explores new technology for vehicles. But more and more, the team looks closely at how all the infrastructure, operations, and new vehicles come together for a more sustainable flying future.

"We are the ones architecting what the system should look like and what breakthroughs it will take to get there," Mavris said.

Consider the matrix of issues with new types of fuel or propulsion systems.

How would new kinds of sustainable aviation fuels be transported to an airport such as Hartsfield-Jackson Atlanta International Airport? New pipelines would have to be built, or new nearby facilities established so fuel could be trucked in.

Current restrictions on hydrogen means aircraft refueling would have to happen at least 75 feet away from the terminal. Do planes move for refueling? Do passengers board buses to get to their plane on the tarmac?

Electric propulsion isn't yet powerful enough for commercial jetliners, but ground equipment could be electrified (and in fact airlines are working on just that). But then airports need charging infrastructure. And that's aside from the resources needed to offer charging for personal vehicles and rental car fleets.

And if an ATH2ENA-like design does become the future of passenger travel, adjustments will certainly be needed at airport terminals to accommodate something other than tube-and-wing planes.

They're all big questions. And they're all challenges Mavris and his team of 50 researchers and 300 graduate students are fully engaged in.

"The field is pretty vast, you know. I think we're in a very unique nexus of capabilities and size," Mavris said. "We have enough volume and resources and credibility — and that also helps in attracting the very best students in the domain."

Dimitri Mavris discusses ATH2ENA with ASDL researchers and students. From left: Ariadne Papamichou, Mavris, Christian Perron, Jai Ahuja, Brinley Rawson, and Sarah Treece.

Sarah Li with a map of a typical day's air traffic.

CANDLER HOBBS

Gaming Out Air Traffic

As Marilyn Smith noted, the complicated operations of autonomous air taxis or package delivery drones would add complexity to our airspace. And that's atop the growing congestion from conventional air travel.

Newly arrived AE Assistant Professor Sarah Li is applying the principles of game theory to air traffic routing and management.

Typically, planning for flights happens a year or more out, allowing for route and timing adjustments to avoid conflicts. Then during actual flight operations, air traffic controllers monitor a portion of the sky to ensure aircraft avoid each other and make it safely to their destinations. As new kinds of vehicles traveling shorter routes in more confined spaces start to contribute to that mix, it's going to be too much for the current system to keep track of.

"Traditionally, maybe it didn't make as much sense to apply game theory here, but now I think it will," Li said. "We're losing some of that centralized structure. Imagine you order something from Amazon in the morning — and let's say advanced air mobility happens. Amazon is going to ship it out in the afternoon. You maybe get a six-hour window to insert that flight trajectory into the current system. We can't manage air traffic the same way we do now, where we have two years' lead time to deconflict everything."

Li sees her work augmenting human controllers trying to process and account for all the constantly updating information available to them. Her models might pull in all that data and suggest optimal routes to avoid conflicts or circumvent developing weather issues. This kind of partnership could mean better overall air traffic handling.

"Controllers have some idea of what's going on broadly, but they are mostly focused on local traffic control. Let's say there are three or four different routing options that they're more or less OK with locally. Maybe our models could suggest, based on global weather information or global forecasted traffic, you should choose this one if you can," Li said.

To oversimplify, Li's models have three main parts. First, they deal with multi-agent systems — in other words, all the individual vehicles using airspace at the same time — and the constraints and objectives for each of those agents/aircraft. Those objectives might be to arrive at their destination on time and use the least amount of fuel.

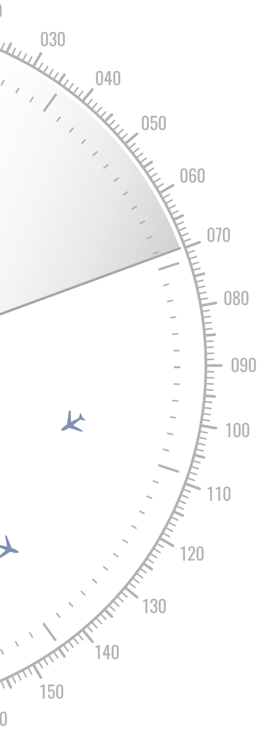
Second, the model accounts for the system's dynamics: Behavior and activity change over time, and they happen in sequence. And third, the model incorporates uncertainty: weather forecasts, miscommunications, delays on the ground, and more.

What makes game theory an interesting approach, Li said, is that the objectives of any one flight might be in conflict — or at least affect — other flights. Every "agent" in the system can't achieve its on-time, fuel-efficient objective without routes that would cause collisions or at least very close calls.

"We want to optimize the objective given constraints," Li said. "Now these objectives and constraints are coupled to another optimization problem, they're coupled with respect to each other. That's game theory."

She said it's a valuable approach for thinking about managing the realities of ever-busier skies.

"Game theory is a good framework where now you can look at these multi-agent systems and how their decisions affect each other."



Predicting Flutter to Prevent It

AE Assistant Professor Cristina Riso is using computational methods to predict and understand how new kinds of aircraft — such as eVOTLs — will vibrate in flight as a result of their interactions with the surrounding airflow.

Riso's work focuses on aeroelastic instabilities that aircraft wings, tilting rotors and propellers, and other aerospace structures might encounter aloft. It's perfectly normal for these structures to vibrate in flight due to turbulence or wind gusts. Typically, the vibrations end fairly quickly.

However, when they continue to grow in amplitude, it's called a flutter instability — and it's a key safety consideration in developing aircraft. Riso is working on methods to predict, understand, and prevent flutter early in the design phase. The methods also may be useful for other structures exposed to fluid flows, including large-scale wind turbines or even rotorcraft used to explore other planets.

"We are interested in developing methods that can be used across the spectrum of aerospace," Riso said. "That could be an existing conventional aircraft that we try to make lighter-weight or more aerodynamically efficient, which requires us to understand how design changes impact in-flight vibrations. But also, we want to understand how to design new configurations."

Engineers know a lot about flutter for conventional airplanes and helicopters, but they don't have the same mature knowledge for emerging designs. For example, aeroelastic instabilities such as flutter can be intensified in proposed aircraft designs with lighter-weight, longer wings and in completely new configurations for air taxis or cargo drones. Riso said it's key to understand those issues early on and optimize designs from the get-go.

"If you find the problems later, such as when performing flight tests, then you have to alter your design in suboptimal ways and delay the development process," Riso said. "By having systematic ways to characterize these instabilities and potentially consider them earlier in the design phase, we may achieve better performance than the current process produces while maintaining safety standards."

Some of the projects in Riso's Structural Dynamics and Aeroelasticity Research Lab are focused on predicting instabilities for tilt-rotor and wing-propeller designs akin to what German and his team are exploring for the RAVEN.

Engineers encountered flutter instabilities in the 1960s in aircraft with flexibly mounted engine-propeller combinations. Called whirl flutter, it resulted in several major crashes before new prediction methods and design guidelines solved the problem. Now it can be an issue again.

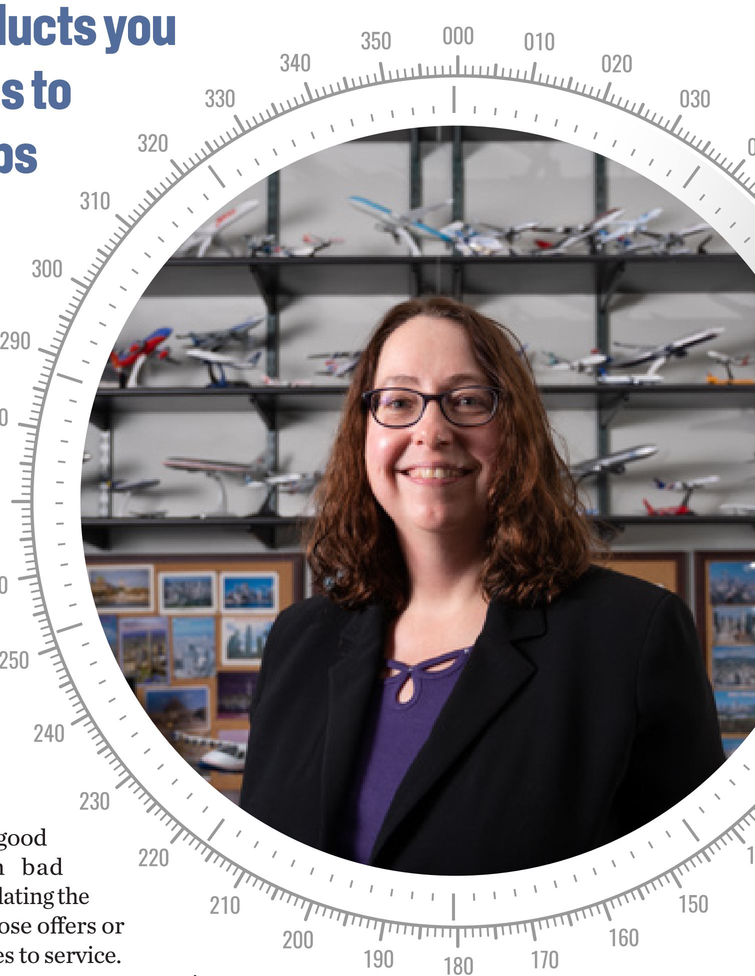
"What was, at some point, a solved problem in the aerospace field has become a significant design challenge and highly active research field again, thanks to the push for new aircraft designs for more sustainable air transportation and the emergence of tilt-rotor and multi-propeller concepts for advanced air mobility," Riso said. "These configurations are designed to be lighter-weight and more aerodynamically efficient. That makes for a more flexible structure, which exacerbates aeroelastic instabilities."

The Riso group discusses flutter. Front row, from left: Cristina Riso, Isabelle Sanz, and Maia Gatlin. Back row, from left: Gray Simmons, Amit Hegde, and Michael Hartim.

CANDLER HOBBS

"We're the math behind the scenes building a better airline experience, offering you products you actually want to buy and lower prices to consumers without steep price jumps you may see right now."

Laurie Garrow



Bundling Better Service for Passengers

After all this talk about new aircraft designs, air taxis, and managing air traffic, what about the traveling public?

In Laurie Garrow's Air Transportation Lab at Georgia Tech (ATL@GT – get it?), researchers are working closely with airlines and travel technology companies to anticipate demand for air travel and develop new ways of packaging flights that benefit flyers and operators.

With airline and industry partners — among them United, Alaska, and Atlanta's hometown airline Delta — the lab is developing next-generation models and simulations to balance customer demand and airline revenue.

"We are like the auditor. I'm not advocating for one particular revenue management system or one particular airline," said Garrow, professor in the School of Civil and Environmental Engineering and AE. "Our role is to be neutral and guide development for the industry, to really evaluate pros and cons."

The air travel industry is investing in new technology that will allow creation of customized bundles for individual consumers and allow consumers to compare similar offers across airlines. It's a new, modern, and standardized communication protocol. And it will mean, for example, more tailored options for flyers and less significant price jumps between fare classes.

Travel packages could include a checked bag, advance seat assignments, or premium lounge access. But they also could include new kinds of nontraditional offerings — maybe free or discounted stopovers to break up long-haul flights. Garrow said the possibilities are vast. And the research need is helping airlines figure those out.

"We're the math behind the scenes building a better airline experience, offering you products you actually want to buy and lower prices to consumers without steep price jumps you may see right now," Garrow said. "We're helping the airline industry stay profitable by finding good ideas and helping them better implement those ideas."

The lab's tools can help airlines decide what offers to create for customers, how to price them, and how to promote them to flyers. Their algorithms allow airlines to separate good ideas from bad ones by simulating the impact of those offers or other changes to service.

"Revenue management is such a strong lever. Small changes can have huge impacts on the bottom line or lead to huge losses," Garrow said. "The value proposition we bring is this ability to model almost the full airline industry — competitive networks, competitive pricing, and revenue management — and allow researchers and industry partners to test out new ideas and quickly evaluate their impact."

Garrow said her team's work also helps airlines consider aircraft design questions and anticipate customer needs. They can help decisionmakers figure out when planes need more seats with extra legroom or more premium seats, for instance.

Garrow has long been a go-to resource for the industry. So, when the founder of a research consortium at MIT retired a few years ago, she worked quickly with eight airline and industry partners to establish ATL@GT. Along with research, those connections have also led her to create a graduate-level course on airline revenue management to fill a gap center members identified.

"No two companies are the same, so our role is coming up with a portfolio of the most important research questions that will benefit the industry and consumers." ◂

ALLISON CARTER

SPA

This photo was taken from the International Space Station above the Pacific Ocean, looking across the city lights of northwest America.

BY JASON MADERER

19

CE

THE CURRENT FRONTIER

OUR ENGINEERS HAVE THE SOLAR SYSTEM COVERED, WITH PROJECTS HUNDREDS — OR MILLIONS — OF MILES FROM HOME.

Right now, about 70 million miles away, a Ramblin' Wreck from Georgia Tech streaks through the cosmos. It's a briefcase-sized spacecraft called Lunar Flashlight that was assembled in a Georgia Tech Research Institute (GTRI) cleanroom in 2021, then launched aboard a SpaceX rocket in 2022.

The plan was to send Lunar Flashlight to the moon, where the spacecraft would shoot lasers at its south pole in a search for frozen water. Mission control for the flight was on Georgia Tech's campus, where students in the Daniel Guggenheim School of Aerospace Engineering (AE) sat in the figurative driver's seat. They worked for several months in 2023 to coax the craft toward its intended orbit in coordination with NASA's Jet Propulsion Lab (JPL).

A faulty propulsion system kept the CubeSat from reaching its goal. Disappointing, to be sure, but it opened a new series of opportunities for the student controllers. When it was clear Lunar Flashlight wouldn't reach the moon and instead settle into an orbit of the sun, JPL turned over ownership to Georgia Tech. It's now the only higher education institution that has controlled an interplanetary spacecraft.

Lunar Flashlight's initial orbit, planned destination, and current whereabouts mirrors much of the College of Engineering's research in space technology. Some faculty are focused on projects in low earth orbit (LEO). Others have an eye on the moon. A third group is looking well beyond our small area of the solar system.

No matter the distance, though, each of these Georgia Tech engineers is working toward a new era of exploration and scientific discovery.

NASA

CLOSE TO HOME

10 TO END
More about Jud Ready's work on page 45

Brian Gunter with one of the RANGE satellites.

"Low earth" is the area that extends about 1,200 miles above our planet's surface. To avoid falling back toward the ground, anything in LEO must circle Earth at about 17,000 miles an hour. The majority of satellites and the International Space Station are in this zone.

Georgia Tech's LEO contributions stretch back to 1984, when the Space Shuttle Challenger ferried a 30-foot spacecraft — NASA's Long Duration Exposure Facility — into orbit, where it remained for seven years. On board was an experiment led by GTRI's Don Blue that studied how space's harsh environment affects materials and opto-electronic components.

In 1998, GTRI designed a radio antenna for the still-under-construction International Space Station. It was installed to provide communications to astronauts waiting in air locks prior to spacewalks.

Fifteen years later, Jud Ready — from GTRI and the School of Materials Science and Engineering — created carbon nanotube arrays that went to space aboard a nanosatellite called ALICE.

Things began to accelerate around that time with the arrival of a pair of AE School faculty members. Brian Gunter joined in 2013, bringing expertise in orbits, satellites, and more. Glenn Lightsey came two years later from the University of Texas at Austin, where he had built and flown several CubeSats. The small satellites were quickly gaining popularity in the aerospace community because of their small size and low cost.

Gunter soon began working on the Ranging and Nanosatellite Guidance Experiment (RANGE) mission, a pair of satellites designed to follow each other in orbit with a goal of improving positioning capabilities of small nanosatellites, which have a mass of 10 kilograms or less. RANGE launched in December 2018, becoming Georgia Tech's first small satellite to reach orbit.

Another CubeSat designed, fabricated, and tested on campus caught a lift to space a few months later. Prox-1 rode aboard a SpaceX Falcon Heavy in June 2019. The project, co-led by Lightsey and former Professor of the Practice David Spencer, was two satellites in one: It carried and deployed LightSail, a solar sail demonstration mission built by the California Polytechnic State University. Both spacecraft continue to circle the Earth six years after their deployment.

Seven more launches carrying Georgia Tech projects flew in the next three years as the College's researchers built a small spacecraft pipeline that continues today. Another dozen or so projects are expected to launch in the next three or four years.

Gunter attributed Georgia Tech's accelerated presence in LEO to two developments. First is the increased access to space made possible by programs sponsored

GUNTER: CHRISTOPHER MOORE; EARTH: NASA

by NASA, the National Science Foundation (NSF), and the Department of Defense. Many of those programs specifically promote ridesharing for small satellites created by universities.

The second is the growth in skillsets and resources on campus. He and Lightsey are continually seeking out and investing in "smallsat" opportunities.

"These projects take a full range of skills: systems engineering, software development, structures, electrical systems, and flight operations," said Gunter, associate professor and director of the Space Systems Design Lab. "It takes large teams of students with different backgrounds and years of investment. So, while the opportunities provided by NASA, NSF, and others are open and available to any university, it takes a certain level of determination to manage all aspects of a multiyear mission."

"WE IMPROVE EVERY TIME WE FINISH A MISSION IN LOW EARTH ORBIT, AND THIS ALLOWS GEORGIA TECH TO BE MORE COMPETITIVE FOR FUTURE OPPORTUNITIES."

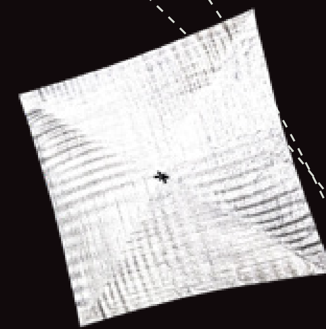
Brian Gunter

Gunter's lab currently includes nine faculty members and more than 90 graduate students — all focused on space-related research. That means they have the breadth and depth necessary to manage those complex undertakings. Lightsey said the future missions also are a testament to the past, capitalizing on investments Georgia Tech made earlier this century to create a small spacecraft flight program.

"It fits well with Tech's emphasis on modern applied engineering," said Lightsey, John W. Young Chair and professor. "Before Brian and I arrived, a few people, like Jud [Ready], were doing their own payloads and experiments on the Space Shuttle and International Space Station. We joined and became part of a critical mass of people working on spaceflight projects. We have continued to hire faculty members who work on flight projects, and that's created a culture of spaceflight missions at Georgia Tech.

"Meanwhile, spacecraft have been getting smaller and less expensive, and launches occur more frequently," Lightsey said. "All of this has made it possible for universities to have active flight programs."

The next set of projects bound for orbit include more CubeSats built on campus and new kinds of propulsion systems to power them. For instance, Lightsey's team designed and built the "prop" systems for six small spacecraft that will fly in formation as part of a NASA mission to study the sun. Another system will be constructed for a 2029 mission to test CubeSat technology that could someday study exoplanets.



The Georgia Tech CubeSat Prox-1 (above) launched in June 2019 and deployed LightSail (right).

Gunter's upcoming flights include the creatively (and appropriately) named WEBS (Wireless Energy from Beamed Signals) mission. It's funded by the Air Force Research Lab (AFRL) and the University Nanosatellite Program through a program that tasks researchers with finding better ways to use solar power in space.

The mission calls for AFRL's Arachne satellite to gather energy from its solar panels, convert it to a radio frequency, then beam it to Gunter's WEBS CubeSat hundreds of miles away, where it will be converted back to power. It would be the first demonstration of space-to-space solar power beaming.

Current spacecraft must independently generate and transport their own power. Beaming power across space would instead open the possibility of distributing power wherever it's needed.

"We improve every time we finish a mission in low earth orbit, and this allows Georgia Tech to be more competitive for future opportunities," Gunter said. "The first missions I led were spent focusing on basic subsystems, such as power and communications. Now that those are established, they can be carried forward into future projects and allow us to focus more on the technology being demonstrated. That experience and flight heritage is earned after many years, and it allows us to pursue increasingly challenging missions."

Glenn Lightsey was part of the Prox-1 and Lunar Flashlight missions.

LIGHTSEY: CANDLER HOBBS; LUNAR FLASHLIGHT: NASA / JPL; PROX-1 AND LIGHTSAIL: JOSH SPRADLING / THE PLANETARY SOCIETY

GEORGIA TECH ON THE MOON

Only 12 people have walked on the moon, including Georgia Tech aerospace engineer John Young. In the past two years, however, Tech has returned to the lunar surface — this time with computer code instead of human feet.

Two algorithms created by Associate Professor John Christian and his students have helped guide two landers to the moon using optical navigation (OpNav) techniques Christian has been developing for more than a decade. OpNav uses cameras to help spacecraft know where they are in the solar system.

In February 2024, Christian's algorithms helped Intuitive Machines' Odysseus spacecraft achieve the first U.S. lunar landing since the Apollo program — and the first-ever successful landing by a commercial company. When Odysseus experienced an anomaly with its altimeter, the lander relied on a camera-based technique that was jointly developed by Christian and Intuitive Machines. The method tracked the apparent movement of landmarks from one image to another to help the lander understand its motion relative to the surface, allowing it to land and operate for 144 hours before entering standby mode.

A second Georgia Tech algorithm was onboard Intuitive Machines' follow-up lander, Athena, this past March. It was largely the work of Ava Thrasher, a research engineer in the AE School who first got involved in OpNav research after taking Christian's senior design course as an undergraduate.

She developed a crater detection algorithm that used image processing techniques to identify the centers of lunar craters. Then a second algorithm matched craters in the image to a catalog of known craters to help the spacecraft estimate its position and orientation. The goal was to create a reliable and quick onboard system to guide Athena to its landing site on Mons Mouton near the lunar south pole.

"These missions have given our students unique, hands-on learning experiences," said Christian. "It's been a privilege to provide some of the theoretical underpinnings that are helping to enable this new age of lunar exploration. Our collaborative partnerships with NASA, Intuitive Machines, and others are a perfect example of how academic research can be applied to open new frontiers."

Ava Thrasher and John Christian's algorithms, based on optical navigation research, have been used in recent lunar landing missions.

Intuitive Machine's third lunar lander, expected to launch in December, will deliver an autonomous robotics algorithm developed by AE Associate Professor Yashwanth Nakka. Originally written during Nakka's tenure at JPL, the software will allow a team of three different micro-rovers to cooperatively explore the lunar surface, conducting distributed science experiments without human supervision.

The mission forms the core of NASA's Cooperative Autonomous Distributed Robotic Exploration (CADRE) initiative, which aims to demonstrate scalable autonomy for multiple robots in extreme planetary environments. CADRE is led by Jean-Pierre de la Croix, a three-time Georgia Tech graduate in electrical and computer engineering and computer science.

Nakka joined Georgia Tech in 2024 and is building a research laboratory designed to simulate lunar surface conditions. The lab includes lunar terrain that mimics mechanical interactions on the moon and the optical environment. The lab has engineered rock distributions, crater analogs, and lighting systems that simulate the harsh lighting and thermal gradients of lunar day-night cycles. The facility will support long-duration testing of autonomous teams of robots in varying terrain, lighting, and communication conditions.

"Past missions have mostly relied on a single rover to carry out a limited set of tasks. But deploying a team

THRASHER AND CHRISTIAN: CANDLER HOBBS; MOON: NASA

of robots — each with specialized instruments — unlocks a new operational paradigm," Nakka explained. "Not only do we gain resilience by avoiding single points of failure, we also can enable dense, high-resolution data collection across multiple physical domains. This allows us to characterize the environment in a multi-modal, spatiotemporally coordinated way."

"OUR COLLABORATIVE PARTNERSHIPS WITH NASA, INTUITIVE MACHINES, AND OTHERS ARE A PERFECT EXAMPLE OF HOW ACADEMIC RESEARCH CAN BE APPLIED TO OPEN NEW FRONTIERS."

John Christian

Nakka's work would help develop a major step toward autonomous robotic planetary exploration — where a team of robots adapts, cooperates, and dynamically reconfigures based on mission needs, the terrain they encounter, and the availability of energy. Nakka's group also is developing new hardware, such as morphing rover wheels that can flex in granular terrain and stiffen on solid ground. Their variable tread height provides enhanced traction and energy efficiency across a variety of terrain.

"JPL is a phenomenal place for designing mission-ready technology," Nakka said. "But Georgia Tech gives me the platform to tackle foundational research questions: How do you design and control robotic systems that are adaptable, resilient, and truly autonomous in unstructured, uncertain environments? These are the building blocks for a sustainable robotic presence on the moon, Mars, and beyond."

CANDLER HOBBS

23

OTHER WORLD EXPLORATION

After earning his undergraduate physics degree from Georgia Tech in 1984, then going to grad school, John Cressler joined IBM to work on mixing silicon with germanium to create a new alloy for electronic chips. The team discovered that the combo was faster and more powerful than silicon alone. The technology revolutionized the electronics industry and now helps power GPS, WiFi, smartphones, and countless other modern devices.

Cressler continued his silicon-germanium (SiGe) research as a professor at Auburn University in the mid-1990s. One day, his Department of Defense program director asked if he had ever considered how SiGe would function in a radioactive environment. Cressler knew very little about the subject but agreed to explore it. It led to the world's first SiGe radiation experiment.

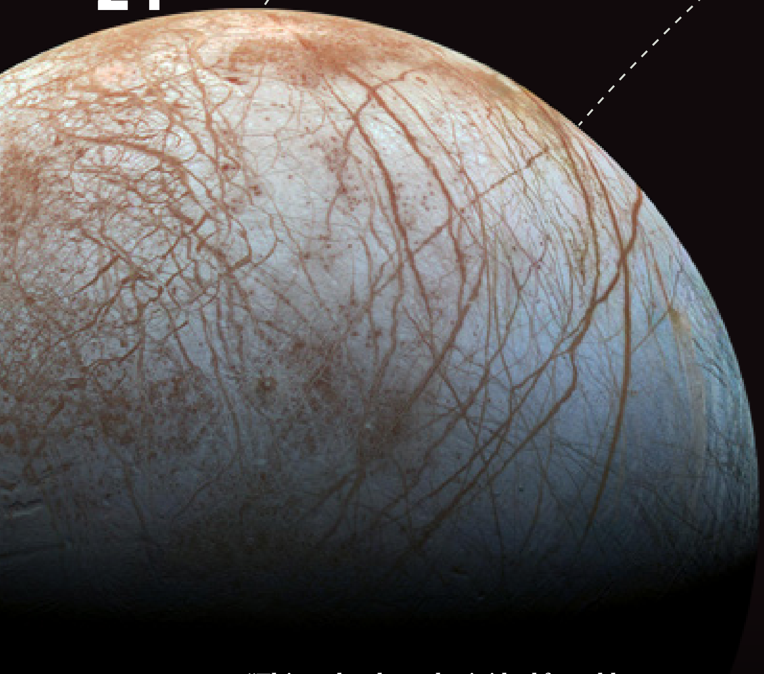
"When nothing happened the first time, I asked my students if they did the experiment correctly," said Cressler, Regents' Professor and the Schlumberger Chair in Electronics in the School of Electrical and Computer Engineering (ECE). "We did it again, and nothing happened again. That's when we learned SiGe is resistant to radiation."

The discovery made Cressler a pioneer in the field. It also led him to space research. A current NASA project has him developing the electronics infrastructure for future missions to Europa, the most radioactive moon in the solar system.

Europa sits firmly in Jupiter's magnetosphere and is constantly pelted with radiation. A typical medical X-ray delivers a radiation dose of .01 rem; a day on Europa would deliver 540 rem. Visiting Europa would kill a person, but it's perfect for SiGe. It's also considered the best place in the solar system to find life because it has a water ocean 10 kilometers below its surface.

Cressler and his students have already created an SiGe radio frequency receiver that successfully worked while being exposed to Europa-like conditions.

John Cressler's discovery of silicon-germanium's radiation resistance led him to space research.



"HAVING A TEAM OF SMALL-SCALE ROBOTS WITH MANY SENSORS WOULD ALLOW US TO EXPLORE MORE EFFICIENTLY. THE REDUNDANCY CAN ALSO HELP OVERCOME THE FACT THAT SOME MACHINES WILL INEVITABLY FAIL DURING THE MISSION."

Azadeh Ansari

"This technology also is ideal for cold temperatures, which makes Europa even more ideal for SiGe transistors because its surface temperature is minus 300 degrees F," said Cressler, who's also talking to NASA about how the same kind of tech can be used for missions on Earth's moon and its permanently shaded craters, which are even colder. "I was always interested in space as a kid, so working on a technology that is ideal for space has always jazzed me. There's nothing cooler than thinking my stuff might enable humans to discover life someplace else someday."

Whenever a rover arrives on Europa, the idea would be to drill through the surface ice until reaching water, then release a fleet of swimming robots to explore the ocean. That's where Cressler's ECE colleague Azadeh Ansari plays an important role. She specializes in building small robots equipped with sensors. She's fabricated and tested sensors with JPL that would measure Europa's water temperature, pressure, acidity, chemical composition, and more. Ansari's chip would ride on JPL's SWIM (Sensing With Independent Microswimmers) robots. It's the first chip to combine so many sensors for ocean composition identification into a one-millimeter-sized package.

"Large robots are extremely limited in the water volume they can explore," said Ansari, associate professor in ECE. "Having a team of small-scale robots with many sensors would allow us to explore and map a larger water volume more efficiently. The redundancy can also help overcome the fact that some machines will inevitably fail during the mission."

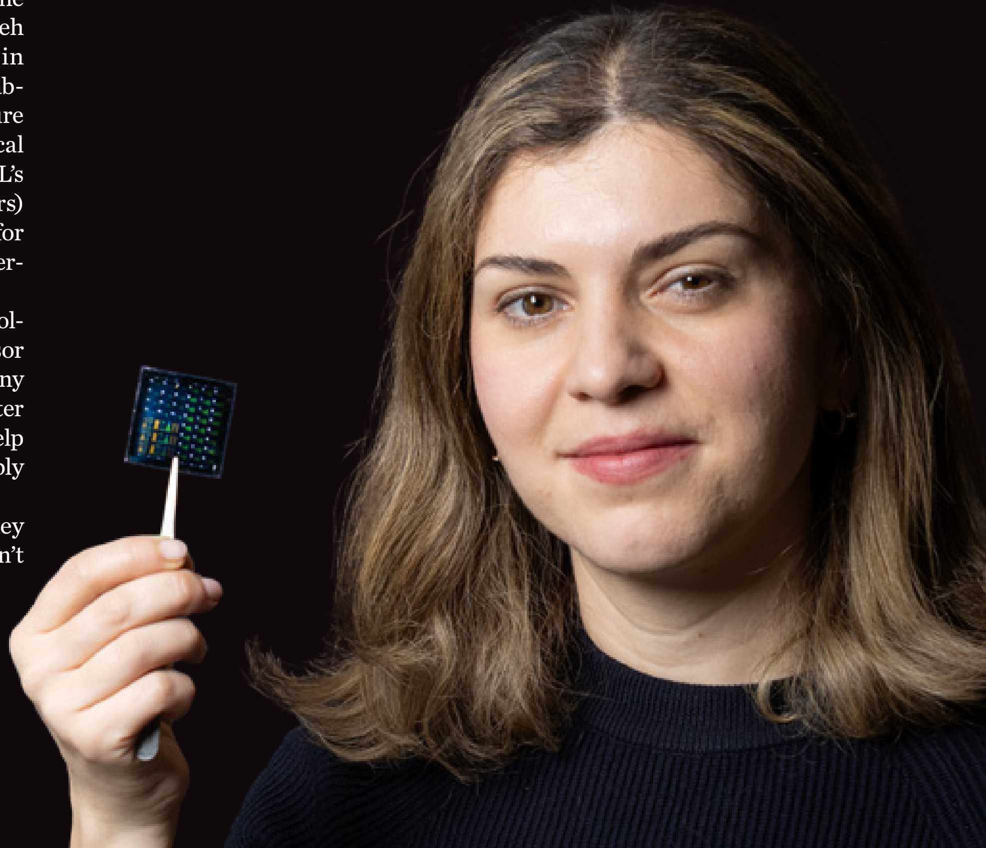
Ansari's next task is packaging the sensors as they prepare for mysterious ocean conditions. Scientists don't yet know how salty or acidic Europa's waters are, making it difficult to match the packaging with its eventual underwater environment. Her team will test sensors in frigid Alaskan waters and other areas around the world.

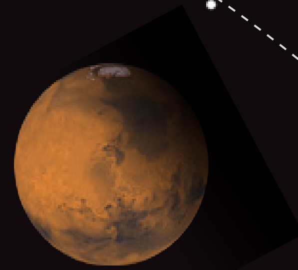
Closer to home, and someplace a lot warmer, Chris Carr is on the science team that will explore the clouds of Venus in 2026. The AE assistant professor and his students are working on the Venus Life Finder mission with MIT and a company called Rocket Lab. They'll send a probe to Earth's "evil twin" to search for signs of organic chemistry in its atmosphere. It will be the first private spacecraft to reach Venus, and the first U.S. mission to study its sulfuric acid-filled clouds in nearly 50 years.

Carr's team helped oversee the development of the spacecraft's autofluorescence nephelometer (AFN), which was built by Droplet Measurement Technologies. As it races through the Venusian atmosphere, the instrument will fire a laser through the clouds and use light scattering to measure the size and composition of the

Left: Long, linear cracks and ridges crisscross the surface ice of Europa.

Below: Azadeh Ansari has developed a chip that combines many sensors into one small package.





Chris Carr and his team flew a test craft through Hawaii's volcanic fog clouds to gather baseline data for a 2026 mission to Venus.

planet's aerosols. The mission will also measure fluorescence, which Carr called a smoking gun for possible organic materials.

"While I don't think there is life as we know it in those clouds, it's important to better understand Venus' chemistry," said Carr, who has a joint appointment in the College of Sciences' School of Earth and Atmospheric Sciences. "Sulfuric acid and water have different properties, which can contribute to or limit the kind of chemistry that can occur. By understanding what might be possible, we can learn if different types of life might be possible. It also helps us know what to look for when we look for life."

Carr's team tested the AFN in March, flying it through Hawaii's volcanic fog clouds, which are rich with sulfuric acid droplets. The measurements will serve as an important baseline to compare against what will be gathered on Venus. The probe will collect data for just five or six minutes and continue transmitting data to Earth for another 10-15 minutes before it exceeds its design limits and disintegrates. All after a journey that will take three to four months.

Carr's work extends to our other planetary neighbor, too. He's serving on a National Academies committee outlining the science priorities for the first crewed missions to Mars. He's also sent several experiments to the International Space Station to learn more about how bacteria grow so that scientists can better fight antibiotic-resistant bacteria on long-duration space missions.

Crewed deep-space flights also are the focus for the AE School's Álvaro Romero-Calvo. He's working with NASA to find better ways to make oxygen for astronauts. Current systems aboard the International Space Station use electrolysis to separate water into hydrogen and oxygen. The machines are bulky with many moving parts. Backup equipment is stored on the station in case repairs are needed. And should a critical emergency occur, the crew could quickly return to Earth.

None of this is practical for an isolated astronaut crew millions of miles into their journey to or from Mars. Their smaller spacecraft will need simple, reliable systems. Carrying spare parts means more mass, and flying with more mass is more expensive. A quick return home in an emergency would be impossible.

Romero-Calvo is working with NASA on an oxygen system with no moving parts. He's also splitting water into hydrogen and oxygen in microgravity using electrolysis. But Romero-Calvo then uses magnets to extract the oxygen, creating a process that avoids the need for a forced water recirculation loop, pumps, and centrifuges.

Mars-bound astronauts breathing Romero-Calvo's magnet-made oxygen. Cressler's transistors reaching Europa. Ansari's sensors swimming in an ocean 400 million miles away. They're all projects and missions that might not be a reality for at least a decade. But preparing for the future is what excites Ansari the most.

"Sure, our projects are a little blue sky. I know they won't happen soon," she said. "But it's good to think about ideas that are far away. That's the role of academia — to think ahead to projects, ideas, and solutions that will be deployed many years into the future." ◂

ANSARI: CANDLER HOBBS; CARR COURTESY: CARR; EUROPA, VENUS, AND MARS: NASA

BY JASON MADERER

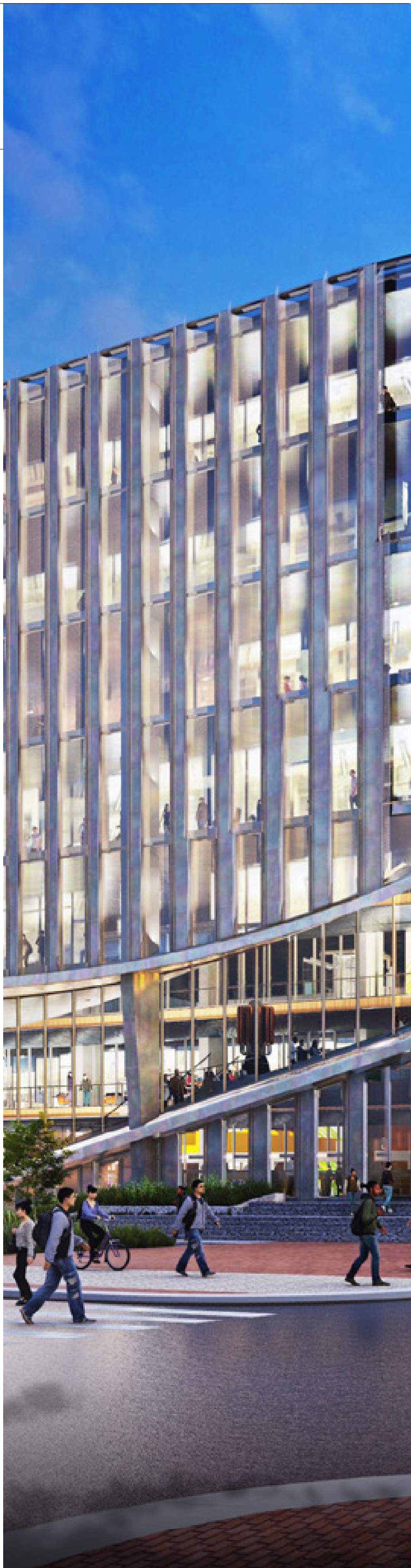
STUCK IN THE SIXTIES,

BUILDING FOR THE FUTURE

The last time Georgia Tech opened new aerospace engineering buildings, humans had yet to walk on the moon.

And two of the four main buildings dedicated to AE were built in the 1930s, when cloth still covered many airplane wings and Tech students took classes about piston engines and hydraulics.

That's four structures housing the nation's No. 2 AE program, and they're older than most current students' parents. Even with renovations and improvements over the years, the leader of the Daniel Guggenheim School of Aerospace Engineering says its time — beyond time — to upgrade.



Left: The School has outgrown the Guggenheim building, completed in 1931, and other existing facilities.

Opposite page: A new building like this preliminary concept will keep Georgia Tech's aerospace program competitive into the future.

PERKINS AND WILL

AE BY THE NUMBERS

135K sq. ft.
Aerospace engineering's approximate current footprint

200K+ sq. ft.
Projected area of a new building — including a mission control center, drone lab, flexible classrooms, and fully-instrumented lecture halls

58%
Total enrollment growth in aerospace engineering since Fall 2017

Left: Interior concept for the new building.
Inset: The School's current mission control room in an attic space.

RENDERING: PERKINS AND WILL; INSET: CANDLER HOBBS

"The truth is, we needed a new building 35-40 years ago, when computing, electronics, and sensors started to revolutionize the aerospace industry," said Mitchell Walker, the W.R.T. Oakes Chair of the School. "Aerospace has since become a foundational tool. It is the infrastructure we use to move people and products around and beyond Earth. Aerospace, via satellites, is also how we exchange the information that powers our global economy."

The other truth is that the School is bursting at the seams with the largest enrollment among the nation's public aerospace programs. Walker said astrobiology research is limited because AE lacks dedicated wet labs and fume hoods. Researchers can't do experiments related to lunar and Martian regolith because AE buildings lack high-end ventilation systems. And two of the main areas where students gather to work and study — the Loewy Library and AE computer lab — each fit about 50 people. That's less than 3% of the student population.

"Our mission control room, which communicates with Georgia Tech-built spacecraft, is tucked into a small attic with wooden rafters," Walker said. "After walking up three flights of stairs to a cramped space, our students and faculty do amazing work in that room. But when NASA, commercial space companies, and other high-end sponsors come to visit, it looks like a shoestring operation. It hurts our competitiveness when the workspace doesn't match the quality of service we're able to provide."

Walker said it's time for the quality of the facilities to match the quality of the learning, discovery, and innovation that happens in those places.

"We're the country's No. 1 public aerospace program, and we attract world-class faculty," he said. "Just imagine how much more we'd accomplish — for students, for the industry, and for society — if we matched those achievements with new classrooms, labs, and research space."

2031

The year the aerospace engineering program will celebrate its 100th anniversary

1968

The year Georgia Tech's newest aerospace building opened. Peer programs opened new buildings in:

1993 — University of Michigan
2007 — Purdue University
2019 — University of Colorado
2022 — University of Illinois

Aerospace in Georgia

ADOBE STOCK

STATE IMPACT: AEROSPACE IS A MAJOR DRIVER OF GEORGIA'S ECONOMY

AEROSPACE PRODUCTS ARE
GEORGIA'S NO. 1 EXPORT

$12.6B
in 2024

224%
INCREASE IN GEORGIA'S AEROSPACE EXPORTS, 2006-2022
5.6x the growth of aerospace exports nationwide

32%
OF ALL AEROSPACE EXPORTS IN THE SOUTHEAST, 2022
Second only to Florida at 33%

$57.5B
in economic impact

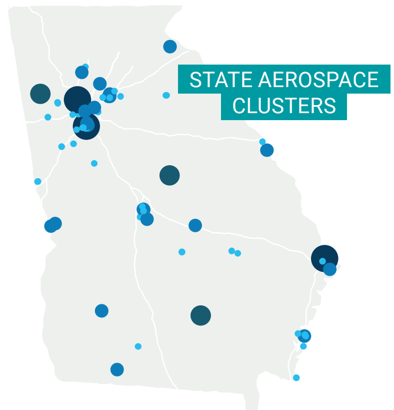
AEROSPACE IS THE STATE'S
SECOND-LARGEST MANUFACTURING INDUSTRY

STATE IMPACT: AEROSPACE EMPLOYMENT

800+
AEROSPACE COMPANIES IN THE STATE

219,400
WORKERS EMPLOYED IN AEROSPACE-RELATED JOBS, 2023

55.6%
OF AEROSPACE EMPLOYMENT IN GEORGIA IS AIRCRAFT MANUFACTURING



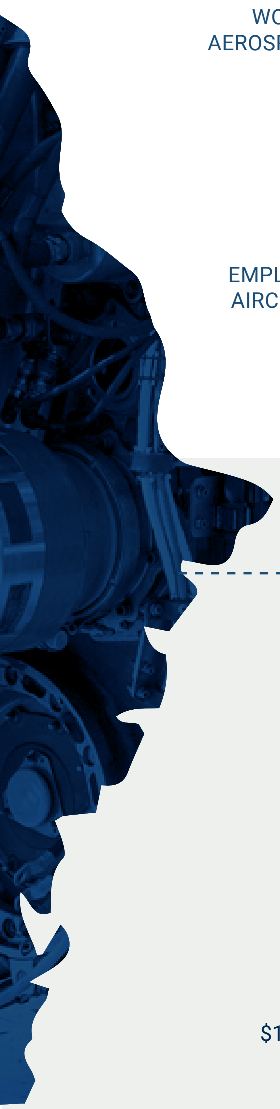
30%
OF GEORGIA TECH AEROSPACE GRADS LIVE AND WORK IN GEORGIA

AEROSPACE IN HIGHER ED

$54M
NEW RESEARCH AWARDS FOR GEORGIA TECH AEROSPACE ENGINEERING, FY24

$936M
GEORGIA TECH R&D EXPENDITURES FOR ENGINEERING, FY22

GEORGIA COLLEGES AND UNIVERSITIES RECEIVED
$1.3B+
IN RESEARCH FUNDING SPECIFIC TO AEROSPACE MANUFACTURING



THE FUTURE OF AEROSPACE

Georgia has a footprint in all four emerging growth areas in the industry:

Space Economy
PROJECTED TO GROW TO $1 TRILLION BY 2040

Autonomous AVs
MARKET PROJECTED TO GROW TO $55 BILLION BY 2030

Sustainable Aviation Fuels
FEDERAL GRAND CHALLENGE TO SUPPLY 3 BILLION GALLONS/YEAR BY 2030

Electric Aircraft
ADVANCED AIR MOBILITY — PARTICULARLY IN URBAN AREAS

GEORGIA.ORG; GEORGIA POWER COMMUNITY & ECONOMIC DEVELOPMENT — AEROSPACE MANUFACTURING, FEBRUARY 2024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NEWS
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BY JOSHUA STEWART
ILLUSTRATIONS BY CHARLIE LAYTON

These Engineers are Flying High

In the air and among the stars, College of Engineering alumni are working every day at some of the world's leading aerospace organizations to innovate, fly safer, and travel farther.

Whether they're exploring space or supporting key national defense operations, Georgia Tech engineers have influence and significant responsibility at the world's biggest and most respected aerospace companies. We asked a few of them to tell us about their work and what they see just over the horizon.

Sarah Walker

DIRECTOR, DRAGON MISSION MANAGEMENT

SPACEX

AE 2009, M.S. AE 2011

"I used to say that if I could live in any other time in history, it would be the Apollo era. But I'm realizing that's not true anymore. Those missions were amazing. They inspired the whole world. **But the things I get to be a part of today are just as amazing."**

My job is three-fold. Externally facing, I'm expected to be something of a bridge or ambassador to our Dragon customers, including NASA and private entities. My goal is to really understand their needs for a mission we will execute for them and SpaceX's needs as we work hard to revolutionize the industry — then find a way to achieve both. I often find myself advocating for our customers' interests to SpaceX internal teams, while simultaneously advocating for SpaceX's interests to our customers.

Internally, I manage a high-performing team that must move quickly, make sound decisions, and ultimately execute our contracts and missions safely, ensuring each mission accomplishes all of its objectives.

Another fun part of my job is speaking to the public at our press briefings before and after Dragon launches. I get to be on console in Mission Control for launch, but there's a part of me that thinks the fun part is before and after liftoff. I get to share to a room full of interested journalists (and hopefully a few kids watching at home — at least my own, anyway!) all about the things that make each Dragon mission so exciting and important. I was a cheerleader at Georgia Tech, and sometimes it feels like I get to put a little of that spirit to use in this part of my job.

Why is that work interesting to you?

This kind of work was really intimidating at first. I studied aerospace engineering at Tech, not human studies or public speaking or negotiation strategy! I didn't expect so much of my job to hinge on empathy and E.Q. — and I expected there to be a lot more calculus! But the calculus of human motivation and team dynamics to accomplish a shared goal of the highest stakes has become incredibly interesting to me over the last several years.

What are you most excited about right now in space?

What excites me the most is how much the work we're doing in this industry actually makes a difference. I used to say that if I could live in any other time in history, it would be the Apollo era. But I'm realizing that's not true anymore. Those missions were amazing. They inspired the whole world. But the things I get to be a part of today are just as amazing.

I've gotten to experience so many game-changing breakthroughs at SpaceX in the span of my own small career. When I joined, SpaceX had launched only four rockets to orbit without exploding. Now we launch more things to space every year than the rest of the world combined. It's insane! To my kids, watching a rocket launch from our porch in El Segundo is just another Tuesday night.

Another was landing rockets and reusing them. It's the inflection point in what some might call the second space age. I vividly remember when that had literally never been done (not even a decade ago), and now my kids ask me why people used to just throw rockets away after flying once! But bringing them back feels like something we JUST figured out how to do. And it's making space so much more accessible to more of the population than it ever has been before. Every little thing I get to work on feels like it moves the needle on something that really matters, and that is incredibly rewarding.

Philip June

VICE PRESIDENT AND PROGRAM INTEGRATION OFFICER FOR SPACE MISSION SYSTEMS

BOEING DEFENSE, SPACE AND SECURITY

ME 2006

I serve large satellite program management leaders and their teams. In general terms, I work to help our programs run more efficiently from proposal through launch. Our portfolio has many programs with billions of dollars of business from the commercial to government sectors. I help manage risks, issues, and opportunities and identify new ways of working through the use of generative AI, data analytics, and other tools. My goal every day is to help one leader or one teammate be better at their work by removing a roadblock or offering my perspective.

Why is that work interesting to you?

Space has long been a passion of mine. I'm sure that I wasn't the only young, budding engineer who watched Space Shuttle launches and looked up at the sky with awe and wonder. I still feel that child-like wonder and curiosity when I learn something new from all the brilliant people I have a privilege to work with every day. That keeps me excited about what I do. It's a real blessing and a privilege to grow up and do what you have passion for and have had lifelong interest in. I'd also add that being a leader working in space is the cherry on top. Leadership has also been a passion of mine since becoming a first-line leader over 15 years ago. I couldn't ask for a more fulfilling career.

What are you most excited about right now in space?

I am most excited about all the investment and innovation driving space forward. After many years of development and partnerships and new business models, we are starting to see innovation not only in products but also in business models and the commercialization of space. It's an exciting and challenging time to be in the business. Ultimately, I believe that what we are experiencing now will push humanity forward in a meaningful way. If you love all things space and aeronautics, there's no better time to be alive.

"What we are experiencing now will **push humanity forward** in a meaningful way."

Farah (Khemani) Zuberi

DIRECTOR OF SPACECRAFT MISSION MANAGEMENT

FIREFLY AEROSPACE

AE 2012

My primary job is to ensure mission success for our lunar and spacecraft payload customers. I started as a payload integration manager at Firefly four years ago when Firefly won its first NASA Commercial Lunar Payload Services (CLPS) contract. I partnered with all subsystem leads to develop a vehicle with compatible payload interfaces and then worked to integrate, test, and operate the lunar payload instruments on our first Blue Ghost lunar lander. It successfully landed and completed its full two-week mission on the moon in March. Now, I lead a team of payload integration managers who support several payload customers — NASA and commercial — for our various spacecraft missions. We have been awarded three NASA CLPS lunar missions thus far.

Why is that work interesting to you?
I work to send and operate science experiments on the moon, and it is as cool as it sounds! The projects I am working on support the efforts to get humans back to the moon and beyond. Space exploration has always been a passion of mine, so making an impact in this field is really important to me.

What are you most excited about right now in space?
Increased public interest in space means there are more initiatives supporting advancements in space exploration, so there is much to look forward to! Before our recent Blue Ghost mission, it had been over 52 years since the U.S. successfully landed and operated as intended on the moon. This mission's 10 payload instruments included science experiments and technology demonstrations, which collected lots of data that is currently being processed. I am excited to see all of the science advances stemming from the successes of this mission and how they drive change for future exploration missions.

"I work to send and operate science experiments on the moon, **and it is as cool as it sounds!** The projects I am working on support the efforts to get humans back to the moon and beyond."

Roderick McLean

VICE PRESIDENT & GENERAL MANAGER – AIR MOBILITY & MARITIME MISSIONS

GENERAL MANAGER MARIETTA, GEORGIA, SITE

LOCKHEED MARTIN

M.S. EE 1993

I oversee the C-130, C-5, and P-3 programs, including profit and loss, program execution, quality, and performance. This role is particularly exciting because I have the opportunity to work on some of the most iconic and enduring aircraft in the world. For example, the C-130 Hercules tactical airlifter program is the longest-running military production program in history, with over 2,700 aircraft produced and still in production today. We are currently producing the C-130J Super Hercules, which is the most advanced version of the airlifter. It's flown by operators in 23 nations in support of 20 different mission requirements. Hercules is a worldwide workhorse whose roots are firmly planted

in Georgia — just a few miles from the Georgia Tech campus.

I'm also the general manager of the Marietta site, which means I'm responsible for the entire site and all the activities that take place here. It's home to almost 6,000 employees and a diverse range of programs and activities — including production of the F-35 fighter jet's center wing, stealth coatings for the F-35, and support for the F-22 Raptor fighter jet. We also have a growing workforce with our Advanced Development Programs organization — also known as Skunk Works™ — that is driving innovation and growth in some of the most advanced areas of aerospace and defense.

It's a challenging role, but it's also incredibly rewarding to see the impact that our work has on the world.

Why is that work interesting to you?

As an engineer, I find my work fascinating because I'm still very much involved in the product itself, even though I'm not doing design work. The reason I've worked at Lockheed Martin for 31 years is because of the mission, the products we develop, and the importance of providing humanitarian aid while protecting freedom and sovereignty — not just for the U.S., but also for our allies. The C-130 plays a critical role in delivering aid and support across the globe as one of Lockheed Martin's key capabilities in providing 21st century security. Knowing that the airplanes we build go into harm's way to support mission requirements for our U.S. and allied operators gives my work a sense of purpose and motivation.

I have the opportunity to see the products we develop come to life, and I know that these aircraft are used to make a positive impact in the world. Whether it's providing humanitarian aid or supporting our troops, I'm proud to be a part of an organization that's dedicated to making a difference. It's a feeling that's hard to describe, but it's a sense of pride, purpose, and fulfillment that comes from knowing that my work is contributing to something bigger than myself.

> "I'm proud to be a part of an organization that's dedicated to making a difference. ... It's a sense of pride, purpose, and fulfillment that comes from knowing that **my work is contributing to something bigger than myself."**

What are you most excited about right now in aeronautics?

One of the most significant advancements is in design approaches. Modern design tools allow us to work concurrently across organizations to design products in the digital space with precision and accuracy. This significantly reduces the time and speed to go from concept to production. We're now able to design a variety of aircraft types — from supersonic and hypersonic vehicles to uncrewed systems — and be more responsive to customer needs. It's the ultimate efficiency, which is what all engineers and customers strive to achieve.

We're also working on advanced systems, such as the X-59 supersonic aircraft, which is developed in partnership with NASA to assess the potential for supersonic flight over land. This project is a great example of how digital engineering is enabling us to design and build complex systems more efficiently. Team members in Marietta have been able to design and contribute to the X-59 project remotely, using digital engineering tools to collaborate with colleagues in other locations.

The use of digital engineering tools allows us to work in a more dispersed manner, while still maintaining alignment and collaboration across teams. This provides opportunities for engineers to be involved in even more exciting projects, both unclassified and classified. The creation of a digital ecosystem around the aircraft is phenomenal in enabling individuals and suppliers to be more impactful and innovative in their design approaches and involvement. ◂

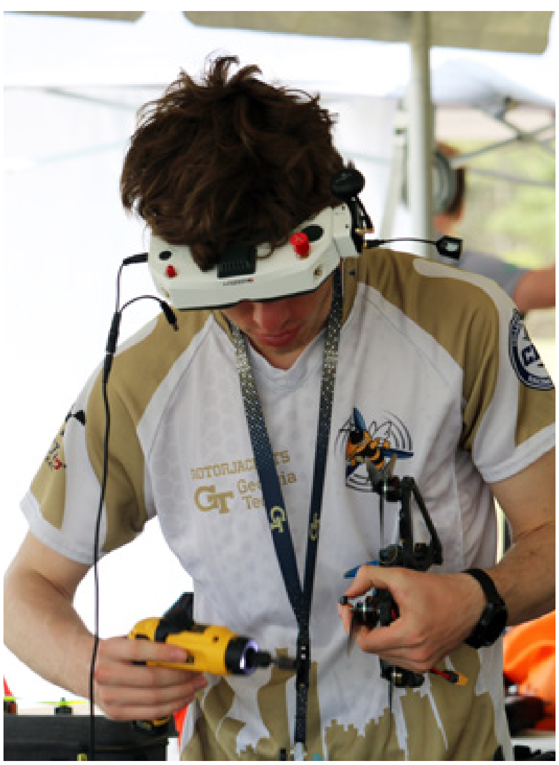
Racing to New Heights

Meet the campus club that's become a powerhouse in collegiate drone racing, built a community of drone enthusiasts, and inspires the next generation of pilots and engineers.

The drones weigh barely a pound and roar through obstacle-laced courses at nearly 100 miles per hour. They zigzag through gates, tunnels, and hairpin turns in a race that's over in less than 90 seconds. One slip and it's game over.

It's a jolt of pure adrenaline for the pilots, who control a blur of speed with instinct and precision. This is collegiate drone racing, and Georgia Tech's RotorJackets are among the best.

Founded less than a decade ago, the student team has become a national powerhouse. The squad has finished in the top four at the Collegiate Drone Racing Championship (CDRC) for the past four years — including back-to-back national titles in 2022 and 2023.



Each drone is custom built by students. Pilots wear goggles outfitted with a live video feed from the drone's perspective. The key is avoiding mid-air collisions.

"Racing is like learning how to run," said second-year aerospace engineering student Caden Perry. "You don't think about each muscle; you just move instinctively. That's what it's like when you're locked in during a race."

Perry came to Tech already fascinated with that first-person-view (FPV) technology. He had experimented with custom drone designs in high school and joined RotorJackets to push his skills further.

"The experience is so immersive that sometimes I forget for a moment I'm on the ground. I'll lean the way I want the drone to go or jerk my head a little to avoid a gate," Perry said.

Like Perry, RotorJackets president Dylan Wyckoff also had experience with casual flying and joined the club to learn about building his own drones. He quickly realized the steep learning curve when he put on the racing goggles.

"The difference between casual flying and racing is like learning to ride a bike versus competing in BMX," said Wyckoff, a fifth-year computer science student. "The first drone I built was five inches. And for a good two months, I couldn't even fly it just because of how hard it was. I spent those two months in a simulator trying to get used to it before I had the ability to actually fly through a racecourse."

It was time well spent. After placing 40th at his first race, Wyckoff climbed to 19th the following year.

> **"There's a misconception sometimes that drones are just for military use or surveillance. We want to show people the positive applications — whether it's in filmmaking, environmental monitoring, or engineering."**
>
> Caden Perry

Research, Outreach, and Cinematography

RotorJackets' impact extends beyond the racecourse. The team regularly collaborates with Georgia Tech research labs, providing expertise to students and faculty working on drone-related studies. The group also hosts outreach events, visiting Atlanta-area K-12 schools to introduce younger students to drone technology.

The group has developed lesson plans to teach high school students about how the machines work and their uses, including some basic CAD modeling and design.

"There's a misconception sometimes that drones are just for military use or surveillance," Perry said. "We want to show people the positive applications — whether it's in filmmaking, environmental monitoring, or engineering."

The RotorJackets have become a go-to source for aerial cinematography on campus.

JAMES TRIMBLE

From capturing homecoming celebrations such as the Mini 500 to filming vehicle tests for the GT Off-Road student competition team, RotorJackets members have built a reputation for stunning footage. They've also worked with Georgia Tech Athletics and other units on campus on specific projects. And sometimes they're just in the air because it's a can't-miss opportunity.

"We've flown around the football stadium and Tech Tower. We worked with the CRC [Campus Recreation Center] to film the pools, the gym area, and on every floor," Wyckoff said. "And during the snow days [in January], we did some filming all around campus to get those winter shots."

Keeping the Club in the Air

Community is a big part of what keeps RotorJackets flying. Thanks to industry sponsors and funding from the Student Government Association, the club has the tools and parts to help new pilots take off. The speed and competitiveness of drone races can make novices wary of putting their treasured drones on a course only to damage or, worse, crash them. The team keeps extra parts, tools, and batteries on hand so members can fix issues, test builds, and keep flying.

RotorJackets has strong relationships with the Daniel Guggenheim School of Aerospace Engineering, the Georgia Tech Police Department, and the Federal Aviation Administration (FAA). The club spearheaded efforts to secure an FAA-Recognized Identification Area over Stamps Field. That allows drones to be flown without remote identification equipment so the team can practice for competitions and hold events for the campus community to get hands-on flying experience.

The group also has a robust Discord server with more than 550 members — students, professional pilots, and drone enthusiasts from across the country who engage in regular discussions, share technical advice, and plan meetups. That community has meant continuity as student leaders graduate and move on, helping establish RotorJackets as a national force.

"We're Georgia Tech," Perry said. "When students get involved and find their passion, they're going to put in the time to make themselves great."

▶ DHANESH AMIN

Top: The RotorJackets team at this year's Collegiate Drone Racing Championship. From left: Adarsh Kumar, Ian Boraks, Caden Perry, Dylan Wyckoff, and Aison Tran.

Above: Dylan Wyckoff navigates during a race.

Opposite page: Caden Perry makes adjustments to a drone.

JAMES TRIMBLE

To Mach 5 and Beyond

Mechanical engineer Anirban Mazumdar and his team are developing the control systems and intelligent algorithms to enable safe flight at incredible speeds for uncrewed — and maybe one day passenger-carrying — hypersonic aircraft.

Imagine boarding a jet in Atlanta and arriving in Japan in about the time it takes now to fly to Miami or Chicago.

That's just one of the possibilities of research in an area of ultrafast flight called hypersonics. The term refers to traveling at roughly a mile a second, or about five times the speed of sound and faster.

Interest in hypersonics is growing, with early notions of high-speed passenger travel alongside defense and space applications driving questions about meeting the demands of Mach 5+ flight.

Such speeds introduce a host of new challenges for aerodynamics, thermal management, and rapid decision-making that Georgia Tech engineers are working to solve.

For Anirban Mazumdar in the George W. Woodruff School of Mechanical Engineering, aerospace questions have always been fascinating. Hypersonics is an area where those questions are tough. Uncovering answers can have real impact on unlocking new capabilities for travel across the globe or to space, in addition to national security implications.

> **"People overlook the fact that the Space Shuttle was a hypersonic aircraft. When the shuttle reentered the atmosphere, it came in at hypersonic speeds. So do the SpaceX systems that come back to Earth. The Apollo capsules did too. Hypersonics is a part of what we do already."**
>
> Anirban Mazumdar

"It's very challenging. We are trying to deal with very extreme scenarios, and we're trying to do it, not just to advance science, but primarily because it matters to our country," Mazumdar said. "That combination is incredible."

The idea of hypersonics may sound new and exotic, but experiments by NASA, the Air Force, and the Navy first applied hypersonic theory to an actual flight vehicle in the 1950s and '60s. The X-15's 199 flights contributed key knowledge to early spacecraft and, later, the Space Shuttle.

"People overlook the fact that the Space Shuttle was a hypersonic aircraft," Mazumdar said. "When the shuttle reentered the atmosphere, it came in at hypersonic speeds. So do the SpaceX systems that come back to Earth. The Apollo capsules did too. Hypersonics is a part of what we do already."

What's growing is attention to vehicles traveling at these high speeds for other uses beyond space missions. The U.S. started actively pursuing development of hypersonic weapons in the early 2000s, with Congress ramping up funding in recent years for research on these systems. Meanwhile, private companies are working to build hypersonic autonomous aircraft for the military and passenger planes to shrink the globe, including work happening in Atlanta not far from Georgia Tech.

In Mazumdar's lab, his team blends modeling and simulations with experimental validations — a combination of basic and applied research made possible by a close relationship between Tech and Sandia National Labs. In fact, in addition to his appointment as assistant professor in the Woodruff School, Mazumdar also is a faculty joint affiliate in the Autonomy for Hypersonics group at Sandia. He spends part of his time working at the Lab and with its hypersonic wind tunnel.

Mazumdar's goal is maximizing safe performance for vehicles traveling at extreme speeds. His team works to develop algorithms and control systems that can handle the physical stresses of those speeds while making safe and appropriate decisions in split-second timeframes. After all, if it takes several seconds to think about something, the aircraft has already traveled several miles before a decision is made.

Heat also is a significant problem at Mach 5 and beyond. Mazumdar is interested in developing ways to manage extreme heat by controlling the way vehicles fly.

CANDLER HOBBS

"This could be relevant to a lot of future flight applications, where vehicles returning from space come through the atmosphere and get very hot," he said. "It's still very difficult to protect them from that heat. One challenge is developing materials and designs that can handle it. But the second question that we're excited about is, can you fly in a different way that enables you to heat up less? Or can you protect certain parts of the vehicle that may not have as much thermal protection? We're interested in how to do that more effectively in the future."

Mazumdar, who came to the Woodruff School in 2018, said Georgia Tech is one of premier places to work on these complicated questions. He pointed to general excellence in engineering. That means researchers can work together across disciplines to tackle all of the relevant areas — materials, design, controls, aerodynamics, and experimentation. He also said the applied research expertise at the Georgia Tech Research Institute (GTRI) and the close collaboration with Sandia create a unique blend of capabilities.

For a long time, research in hypersonics has been led by industry or government agencies. But the role for academic research institutions is growing, thanks to new government initiatives. Mazumdar said those collaborations have expanded who can contribute to developing the technology and were instrumental in giving him early opportunities to study hypersonics.

"Working on hypersonics means exploring exciting scientific challenges that have not been solved, and it's clearly very relevant to our country," he said. "That makes it really fun, to get up and work every day on solving very hard problems that people care about."

▶ **JOSHUA STEWART**

HYPERSONICS ON CAMPUS

Anirban Mazumdar is a member of Georgia Tech's Hypersonics Center of Excellence, a collaboration across campus and GTRI to develop new hypersonic capabilities. The initiative was created to deliver the technologies, testbeds, and talent to drive U.S. success in hypersonics.

Winning the Zero-Sum Game

In the quest to ensure drones and other autonomous vehicles operate safely, engineers have to out-think the malicious attackers who might try to take over.

Control theory, cyber-physical systems, game theory, and reinforcement learning sound like complex engineering and mathematical concepts. And they are.

They're also on the front lines of protecting airborne and underwater drones as well as autonomous passenger vehicles from hackers who might try to take them over and cause death and destruction.

Kyriakos G. Vamvoudakis is at the center of that work. He's an expert in the design of control software for autonomous vehicles that protects against those who would co-opt the vehicles for nefarious purposes.

"We strive to create resilient controllers that can anticipate attackers, mitigate their impact, and decipher their intentions," said Vamvoudakis, the Dutton-Ducoffe Endowed Professor in the Daniel Guggenheim School of Aerospace Engineering. "We apply game theoretic techniques to secure sensors and actuators in large-scale

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cyber-physical systems, such as an airplane or multiple airplanes, multiple drones, flying taxis, cars.

"They'll have different challenges, but our work is more general, and then we try to validate it in different kinds of platforms."

The sensors and actuators he mentioned are critical tools — and prime targets for malicious actors. The goal is to efficiently gather data from onboard instruments, process it, and then adjust control surfaces or rotors accordingly. This involves establishing acceptable data boundaries from sensing devices and defining the movements of actuators.

Vamvoudakis' controllers are meticulously designed to ensure performance and safety: preventing drones from colliding with buildings or other structures, enabling safe operation around other air traffic, and ensuring safety for human pilots or, eventually, passengers. To achieve that, Vamvoudakis, his students, and collaborators, must adopt the mindset of bad actors who would try to exploit these vehicles.

"We have to model them, yes," he said. "We have to always take into consideration what is the worst thing they can do when we compute our defending control policies."

This is where game theory is valuable for their work. It's often a zero-sum game — a winner and a loser. Because the outcome is either that the attacker wins and takes over all or part of the drone/controller or the defender/controller wins by fending off the attack. Designing a system that anticipates the absolute worstcase means the control software can mitigate any attack — and the autonomous vehicle always wins against an attacker.

"Since you know the worst case, you can mitigate anything below this worst case, and you'll be able to guarantee a form of robustness and resiliency," Vamvoudakis said.

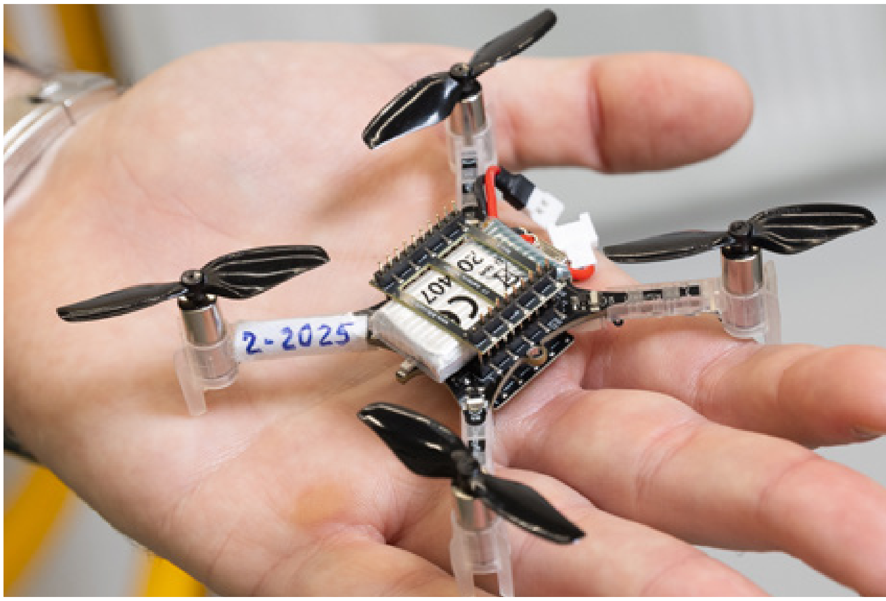
Game theory encompasses the study of numerous "agents" within a system, each with distinct objectives that may influence or conflict with one another. In scenarios involving multiple attackers and defenders, according to Vamvoudakis, this could manifest as a local zero-sum game between an individual vehicle and an attacker, while simultaneously constituting a broader non-zero-sum game.

The ultimate objective, then, is to identify what's called the Nash equilibrium. Named after mathematician John Nash, the equilibrium represents the set of control policies where no agent can improve their outcome by unilaterally altering their strategy.

It's a big ask to compute such complex scenarios, and it's not always strictly necessary. Vamvoudakis' tools model adversaries based on how smart they are. It's an approach that yields significant efficiency in computing the defenses the controller needs to deploy.

"Different attackers have different, let's say, levels of intelligence," he said. "One attacker might be just a random 'player,' so it doesn't do a lot. Another attack might be very smart, with inside information about our

Vamvoudakis' controllers are meticulously designed to ensure performance and safety. … To achieve that, Vamvoudakis, his students, and collaborators, must adopt the mindset of bad actors who would try to exploit these vehicles.



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systems, and then we have to mitigate those effects. So, I find out how smart the attacker is, and then I can compute the policy such that I always win this 'game.'"

Vamvoudakis noted adversaries can be extremely stealthy. Imagine they've planted a piece of malicious code that "hides" in a wind gust. In other words, the attack is triggered by rough air or some turbulence in an effort to disrupt the system surreptitiously. These are the kinds of malevolent realities he and his team have to consider.

How might an attack and defense play out?

Say an adversary tries to override one of a drone's rotors or fools one of its sensors to feed bad data into the controller. Vamvoudakis' resilient controller would identify the attack and isolate that rotor or sensor, relying on the other redundant systems to safely operate.

One of the group's projects uses geofencing to protect restricted areas — perhaps airspace over a military facility or even the White House. With support from the National Science Foundation, they're developing techniques to safely land a drone if it's hijacked and enters a protected area.

The team also works on the security of autonomous and semiautonomous cars and electric vehicles. Vamvoudakis described a possible attack where malware inserted into an EV misreports the status of the battery with the intent of stranding the driver far from charging resources. His team is designing charging infrastructure that's secure from attackers who might use it to insert such a code.

With support from the Department of Defense, Vamvoudakis is developing intelligent agents to work in tandem with human security analysts to monitor drone data for anomalies that indicate an attack. His lab also has funding from NASA, several branches of the military, the National Science Foundation, national labs, NATO, and the Department of Energy.

The machine learning models his team develops are "closed-loop," meaning they constantly incorporate feedback from operations to improve how they perform. There's no pretraining of the models; they work in real time to assess what's happening with the vehicle and how to react.

Vamvoudakis and his team are constantly publishing and sharing their work with the scientific community — including in seven books so far. As a result, they always assume adversaries have more knowledge about the system they're attacking than the researchers do, and they take a working-from-behind approach in building their models.

"I find it fascinating to try to defend systems against adversaries and try to be one step ahead of them," Vamvoudakis said. "I will always have a job to do."

▶ JOSHUA STEWART

Kyriakos Vamvoudakis (left) and postdoctoral fellow José Magalhães test drones and controllers.

CANDLER HOBBS

10 TO END

10 Questions with Jud Ready

Space researcher. Materials scientist. Entrepreneur. And Yellow Jacket. The only thing missing on Jud Ready's resume is "astronaut." Not for lack of trying, though. Ready had hoped earning his bachelor's, master's, and doctoral degrees in materials science and engineering at Georgia Tech would lead him to a spot in NASA's Astronaut Corps. Instead, it's led him to the Georgia Tech Research Institute (GTRI), where his passion for space is alive and well.

Top: Jud Ready with a collection of solar cell samples, similar to those launched to the International Space Station for testing.

BRANDEN CAMP

1 ▸ What about space fascinates you? It all goes back to my dad being interested in space. In first grade, we went to a how-to-use-the-library class, and I came across a book about the Mercury and Apollo astronauts. I checked it out and renewed it over and over again. I eventually finished it in second grade. So, I've had a lifelong commitment since then to space.

2 ▸ What drew you to engineering? I grew up in Chapel Hill. In that same first grade class, we went to the University of North Carolina chemistry department. My mom is really into roses, and they froze a rose in liquid nitrogen then smashed it on the table. It broke into a million bits, and I was like, "What?!" The ability of science to solve the unknown grabbed me. And I had a series of very good science teachers — Mr. Parker in fifth grade, in particular. Then I took a soldering class in high school. We built a multimeter that I still have and still use, and various other things. And I suddenly discovered and started exploring engineering. Plus, I just like making things.

3 ▸ How did your career change from hoping to be an astronaut to being an accomplished materials engineer? When I started looking at colleges, that was my primary interest: What school would help me become an astronaut the quickest. I applied to Georgia Tech as an aerospace engineer, but was admitted as an undecided engineering candidate instead. It was the best thing that could have happened. Later, I got hired as an undergrad by a professor who was doing space-grown gallium arsenide on the Space Shuttle. Ultimately, they offered me a graduate position. I accepted, because I knew you needed an advanced degree to be an astronaut — and for a civilian, a Ph.D. in a relevant career such as materials science.

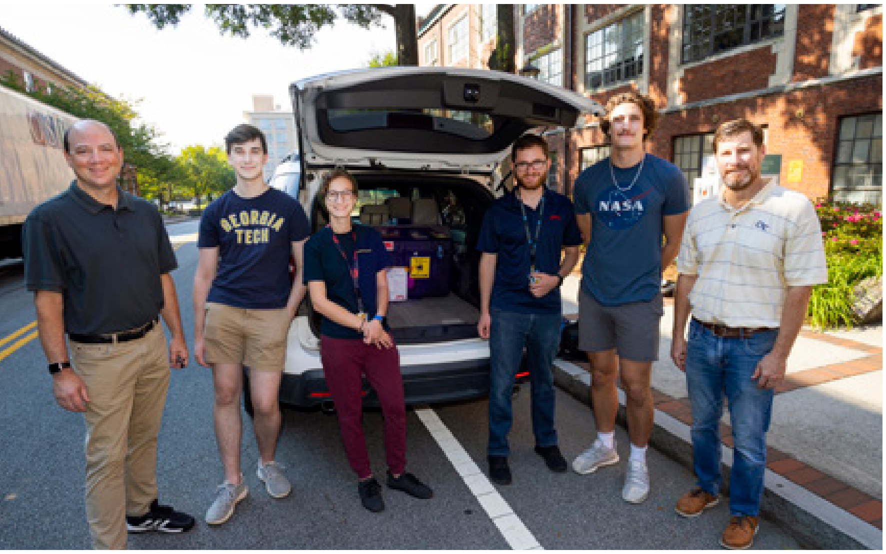
I applied so many times to be an astronaut — every time they opened a call from 1999 until just a few years ago. Never got in. But I was successful at writing proposals and teaching. So I started doing space vicariously through my students, writing research proposals on energy capture, such as solar cells; energy storage, such as super capacitors; and energy delivery like electron emission. They're all enabled by engineered materials.

4 ▸ What makes Georgia Tech and GTRI a key contributor to the future of humans and science in space? Georgia Tech offers us so many unfair advantages over our competition. The equipment we've got. The students. You've got the curiosity-driven basic research coupled with the GTRI applied research model. We've had VentureLab and CREATE-X. Now we've got Quadrant-i to foster spinout companies from research.

5 ▸ One of your solar cell technologies is headed to the Smithsonian National Air & Space Museum. What is it? Early in my career, we developed a way to texture thin film photovoltaics to allow for light trapping. Inverted pyramids are etched into silicon wafer-type solar cells so a photon of light has a chance to hit different surfaces and get absorbed. But thin film solar cells typically don't etch well. I thought we could use carbon nanotubes to form a scaffolding, a structure like rebar. It's mechanically reinforcing, but also electrically conductive. We coat the thin film solar cell material over the carbon nanotube arrays. You've got these towers, and you get this photon pinballing effect. Most solar cells perform best when perpendicular to the sun, but with mine, off angles are preferred. That's great for orbital uses, because the faces and solar panels of spacecraft are frequently off-angle to the sun. And then you don't have the complexity of mechanical systems adjusting the solar arrays. So, we got funding to demonstrate these solar cells on the International Space Station three times, and those are some of the cells we provided to the Smithsonian.

6 ▸ What's it like to have something on display in such an iconic place? The Smithsonian — that's my favorite. My dad moved to D.C. after my parents divorced, and that was my favorite thing to do when I'd fly up there every couple weeks. They're getting cadmium tellurium carbon nanotube solar cells, perovskite, organic, and some CZTS (copper zinc tin sulfide) solar cells — all made at Georgia Tech. I didn't get to be an astronaut, but that feels pretty close, getting our work in that museum. That's very, very special.

7 ▸ Those cells are some of the 15 patents you hold. What other kinds of technologies? Actually, we just got our 16th patent in mid-February. It's for colorizing metal (without paint) by doing special thin film depositions. I've got two devoted to thin-film resistors. Three are the result of mattress spring research with Serta Simmons bedding. Two related to carbon nanotube electron emission for space propulsion. The 3D solar one. Several related to supercapacitors. Another related to microneedles. One is the basis for my spinout company, LZRD Tech, which is a sports performance textile. Another is the basis of my medical device startup, Hub Hygiene. That's a fancy sponge, for lack of a better word, for disinfecting purposes. We have some with Corning for glass for LEDs. It's kind of all over the place, but the unifying point is materials.



Jud Ready (far right) with the Lunar Flashlight team, including Glenn Lightsey (far left), as they prepared to transport the CubeSat from campus to the Marshall Space Flight Center in Huntsville, Alabama.

CANDLER HOBBS

8 ▸ How many of Georgia Tech's space missions have you been involved in? What's the most memorable? Wow, a half a dozen or so. And we just turned over solar cells for the MISSE-22 mission to the space station, and SSTEF-1 to the lunar surface, both launching in October.

Lunar Flashlight is my favorite and most memorable. NASA's Jet Propulsion Lab really helped Georgia Tech come into the big leagues. We also got a connection to the Deep Space Network as a result — one of only four universities to have that. We had NASA engineers on site helping us, working together, and we solved all sorts of problems. And then NASA turned the spacecraft over to us, and that allowed Georgia Tech to do science that's never been done before with an optical navigation experiment.

9 ▸ You teach a very popular course in the materials science of sports at Tech. Where did sports come from? Doesn't look like it fits, does it? My dad liked sports and space, so I like sports and space. I was offered a position on the Athletic Association Board of Trustees. I learned a lot, in particular about student-athlete engagement. They have exit interviews with the student-athletes and ask, "How would you make Tech better?" Over and over, the responses were, "We wish there were more rigorous sports-related courses." And I was like, I can do that. Because the vast majority of student-athletes are not in the College of Engineering, I wanted to have a course that was open to them where they could be exposed to engineering rigor without necessarily being an engineer. We just won an innovation award for how we use Tech's athletic facilities in that class, in fact.

10 ▸ If NASA, SpaceX, or Blue Origin called tomorrow offering you a seat on one of their missions, would you take it? First of all, NASA is not going to call. I gave them plenty of opportunities to call. SpaceX, Blue Origin, other companies that have yet to be announced — heck, yeah, I would go.

It probably won't happen to me but probably will happen for my grandkids. Depends on how fast things go; feels like technology's advancing pretty fast.

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parting shot

Aerospace engineering alumna Farah (Khemani) Zuberi is Director of Spacecraft Mission Management at Firefly Aerospace. She was part of the successful Blue Ghost mission that landed on the moon in March.

▶ MORE ALUMNI IN AEROSPACE, PAGE 32