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FAA's flight plan

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EDITOR'S NOTEBOOK

What we're watching in 2026

X-59 supersonic flights

Artemis II

First air taxi services

Golden Dome progress

2025 was a groundbreaking year for aerospace. U.S. President Donald Trump unveiled the ambitious Golden Dome missile defense effort that is slated to cost at least $175 billion, while NASA readied for its Artemis II flight send four astronauts around the moon.

Those developments make clear 2026 is likely to be even more newsworthy. In this column, we detail what to watch on these issues — and others.

Building Golden Dome

In 2025, Trump shared his plans for a missile defense shield akin to Israel's Iron Dome that he said would be operational before the end of his term. Analysts say 2026 should shed light on the scope of the program's architecture and make clear the major players.

"2026 is when they're going to actually start taking actions, start awarding some contracts," said Todd Harrison of the American Enterprise Institute. "They have all this money; they've got to spend it. And the architecture will start to take shape in 2026 — it will have to if they're going to achieve anything at all by the time the president leaves office."

The sprawling legislative package Trump signed in July included nearly $25 billion for Golden Dome.

"The most important things that will signal that Golden Dome is advancing and will be durable are the following: widespread bipartisan understanding of what it's about and the threats and the concept that it is tailored against, and then likewise the rapid and numerous release of RFPs and, most importantly, putting things on contract," said Tom Karako of the Center for Strategic and International Studies.

He added: "Unless and until things are put on contract and code starts getting written and metal begins to get bent, this is going to remain in the domain of the very interesting, but not especially effectual PowerPoint slide."

Harrison noted the fast pace of the project, the price tag set by Trump and the scope he detailed are likely not all feasible.

"The expectations were set in a way that is entirely unrealistic," he said. "So maybe 2026 is the year when those expectations get normalized and grounded in reality."

Race to the moon

After a turbulent year of funding uncertainty and workforce reductions, all eyes are on NASA as it attempts to send humans beyond low-Earth orbit for the first time since 1972.

The stakes couldn't be higher for Artemis II, said analyst Laura Forczyk of Astralytical. At a technical level, the mission serves as "proof of concept" for much of the technology needed for the Artemis III landing. More broadly, the outcome could help anticipated NASA Administrator Jared Isaacman weigh the distinct long-term architectures favored by the White House and Congress.

"I do think that by" late 2026, "we'll have a much better picture of how Artemis is going to go," said Chris Combs, associate dean of research in UT San Antonio's mechanical engineering department.

Perhaps the biggest near-term decision is whether to change the Artemis III lander, and the answer could hinge on how much progress SpaceX demonstrates with Starship. This year's planned milestones include the debut of the V3 design and the first in-orbit propellant transfer between two Starships.

After most of the 2025 flights ended in explosions, the pressure's on, said Forczyk. "2026 could be a comeback year for Starship, or it could be another slog toward an unknown finish line."

It could also be a banner year for Blue Origin as the company prepares to launch its first lunar lander, the cargo Blue Moon Mk 1. A successful landing "would be a surprise victory" because "they had been seen as the slower player, the turtle in the race," said Forczyk.

X-59 goes supersonic

Boom Supersonic made headlines last year with its demonstration of one method for quiet supersonic flight. Now, NASA is poised to demonstrate another with the X-59 research craft that debuted last year.

The agency hasn't announced a target for the first supersonic flight, but the hope is to prove sonic booms can be prevented through clever shaping of the airframe. So instead of ear-splitting cracks when X-59 breaks the sound barrier, NASA hopes to produce gentle "thumps" no louder than the slamming of a car door.

"This would be a long-term sustainable way to mitigate sonic booms," said Combs. By contrast, Boom's "Boomless Cruise" concept relies on keeping the aircraft at a speed and altitude where the majority of the sound waves refract off the atmosphere, and those that reach the ground are inaudible.

Beginning air taxi service

The electric air taxi industry hopes this is the year that passenger operations begin.

Archer Aviation and Joby Aviation are advancing plans to begin service in the United Arab Emirates, though industry watchers believe these flights could be limited to demonstrations in which the aircraft ferry VIPs, said analyst Sergio Cecutta of SMG Consulting. And in the U.S., several companies plan to conduct limited commercial flights under the Department of Transportation's eIPP, or Electric Vertical Takeoff and Landing and Advanced Air Mobility Aircraft Integration Pilot Program.

Widespread ticketed service in the UAE and elsewhere will likely have to wait until the companies receive FAA type certification, Cecutta said — the first of which could come this year. As of December, Archer and Joby were preparing for Type Inspection Authorization flights, the final stage of FAA flight testing. ★

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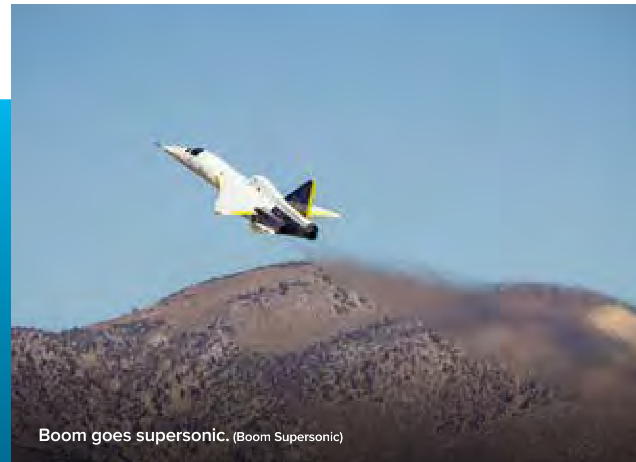
YEAR IN REVIEW 2025

Our annual roundup of the year's biggest events and aerospace achievements, compiled by AIAA's technical community, has gone digital! Scan to read the reports.

Among the most significant events were the Trump administration's proposed Golden Dome missile defense shield, the first flight of NASA's X-59 demonstrator, and continued progress toward integrating drones and electric air taxis into the national airspace.

Blue Origin debuts New Glenn and lands a booster. (Blue Origin)

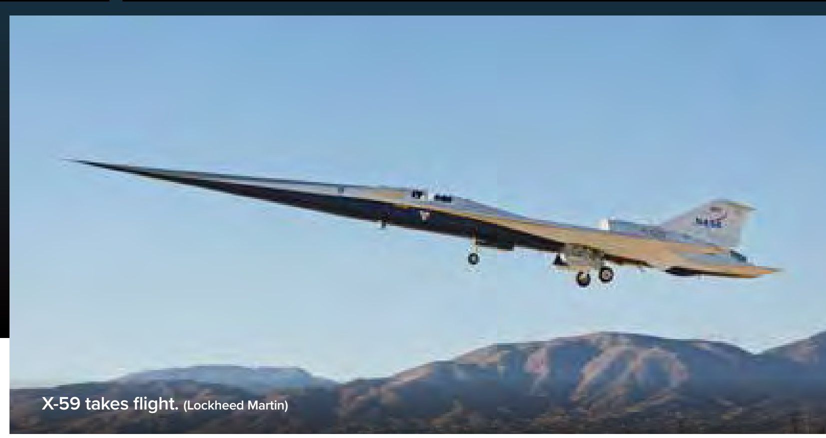


Boom goes supersonic. (Boom Supersonic)

Fatal midair collision near Washington, D.C. (Andrew Harnik/Getty Images)

Firefly's Blue Ghost nails lunar landing. (Firefly Aerospace)

Trump announces Golden Dome. (AP Photo/Alex Brandon)



X-59 takes flight. (Lockheed Martin)

FLIGHT PATH

Aerospace Next

Blue Origin

One year ago, on 16 January 2025, I witnessed the maiden launch of Blue Origin's New Glenn heavy-lift vehicle from Rocket Park on Florida's Space Coast. The landmark mission was awe inspiring with seven BE-4 methane-powered oxygen-rich staged combustion engines burning vividly blue in the tenebrous sky. It was an emotionally charged moment for the launch team as they successfully injected Blue Ring Pathfinder in medium Earth orbit. And it reminded me that breakthrough moments happen across AIAA's member universe year after year.

Breakthroughs don't occur in isolation. They emerge from thousands of engineering conversations, collaborations, and connections. They are the dividends of years of investment in innovation, pursuing design goals that may once have seemed impossible.

Throughout 2025, our industry marked significant milestones in its upward march to a dynamic future. Rockets soared, aircraft demonstrators flew, and landers landed. All the while, growth continued in labs, on tarmacs, and from launch pads where aerospace professionals leaned into complexity, asked harder questions, and pursued bold solutions.

As we enter 2026, our community stands on the threshold of tomorrow. The future of aerospace won't be shaped by a single researcher or "eureka" moment. Rather, necessity will drive experimentation and risk-taking, leading to the next breakthroughs. AIAA will connect people doing this vital work as we look to our north star, to be the most trusted source for aerospace knowledge exchange.

Impact 2025

2025 marked a turning point where ambitious visions became operational realities. Boom Supersonic moved closer to passenger service with its successful XB-1 demonstrator flights. The NASA/Lockheed Martin X-59 demonstrator debuted its supersonic abilities, emitting a sonic thump. The first flights of next-generation autonomous combat aircraft from Anduril and General Atomics demonstrated technologies that will reshape national defense.

New aircraft programs flourished, with an award to Boeing to develop its F-47, the first sixth-generation fighter jet developed under the Next Generation Air Dominance (NGAD) program. Lockheed Martin Skunk Works® introduced its Vectis collaborative combat aircraft, with flight tests planned within two years.

The urban air mobility revolution moved closer to commercial service. Joby, Archer, and other air taxi developers achieved piloted transitions from vertical lift to forward flight, advancing toward FAA-type certification expected in 2026. Electra demonstrated its ultra-short takeoff and landing aircraft for future commercial routes and to support of America's warfighters.

Access to space was fundamentally transformed. Blue Origin went on to land New Glenn's "Never Tell Me the Odds" booster on its second flight, while SpaceX approached an unprecedented 170 launches for the year (as of this writing). Meanwhile, SpaceX's fully reusable Starship completed all Flight 10 objectives, proving that testing and learning remains central to aerospace progress.

Clay Mowry
AIAA CEO

Firefly Aerospace's Blue Ghost made a precision breakthrough, as the first lunar lander under NASA's Commercial Lunar Payload Services (CLPS) program to land upright and remain operational.

Defense innovation shifted into high gear. The Golden Dome for America initiative to develop space-based missile defense dominated discussions with billions of dollars committed toward making in-space interceptors operational. The Space Development Agency continued deploying its Proliferated Warfighter Space Architecture constellation, while hypersonic missile testing cadence increased substantially. Changing acquisition strategies from the Pentagon are expected to significantly increase investment in technology development as part of a broader effort to modernize defense acquisition and enhance America's technological capabilities.

Regulatory momentum matched technical progress. Beyond supersonic flight authorization, the administration streamlined launch approvals, and the FAA released draft rules for routine beyond-visual-line-of-sight drone operations, which is widely recognized as essential for unlocking the full economic potential of uncrewed aerial systems.

The Road Ahead

In 2026, aerospace stands at a technological inflection point. That's why we partnered with BryceTech to produce AIAA's Technology Innovation Forecast. It's our most comprehensive look yet at technologies shaping aerospace through the mid-2040s. Drawing on over 500 survey responses and interviews from AIAA's unmatched technical community, the picture is striking: powerful trends are converging across the air and space domains.

The first glimpse shows that from AI-enabled engineering, quantum computing, and alternative aviation fuel, to advances in fully reusable launch vehicles, hybrid aircraft, and high temperature materials, our community sees a future defined by radical shifts in performance, economics, and national competitiveness. These innovations don't just promise faster or cheaper. They have the potential to reshape how society understands and interacts with aerospace itself.

The full analysis will be published later this month, diving deeper into which technologies are poised to lead, where barriers remain, and how industry and government can position the United States for long-term success.

Consider this an early signal: the foundations of the aerospace next era are already emerging, and our community is uniquely equipped to help shape them.

Welcome to 2026. The aerospace industry has never been more important. Together, we're transforming aerospace into possibly the greatest period of innovation our industry has ever seen. ★

BOOK SPOTLIGHT

A SELECTION OF RECENTLY PUBLISHED AND UPCOMING TITLES

Open Space

RELEASING MARCH 24, 2026 (Penguin Random House)

Space journalist **David Ariosto**, an Aerospace America contributor, takes a look at the future space economy. Ariosto contends a new era of competition and exploration is dawning. He examines the role of space companies, as well as the efforts of multiple nations pursuing their own exploration goals. What technologies will be critical, and who will arrive first?

On a Mission

PUBLISHED OCT. 28, 2025 (Penguin Random House)

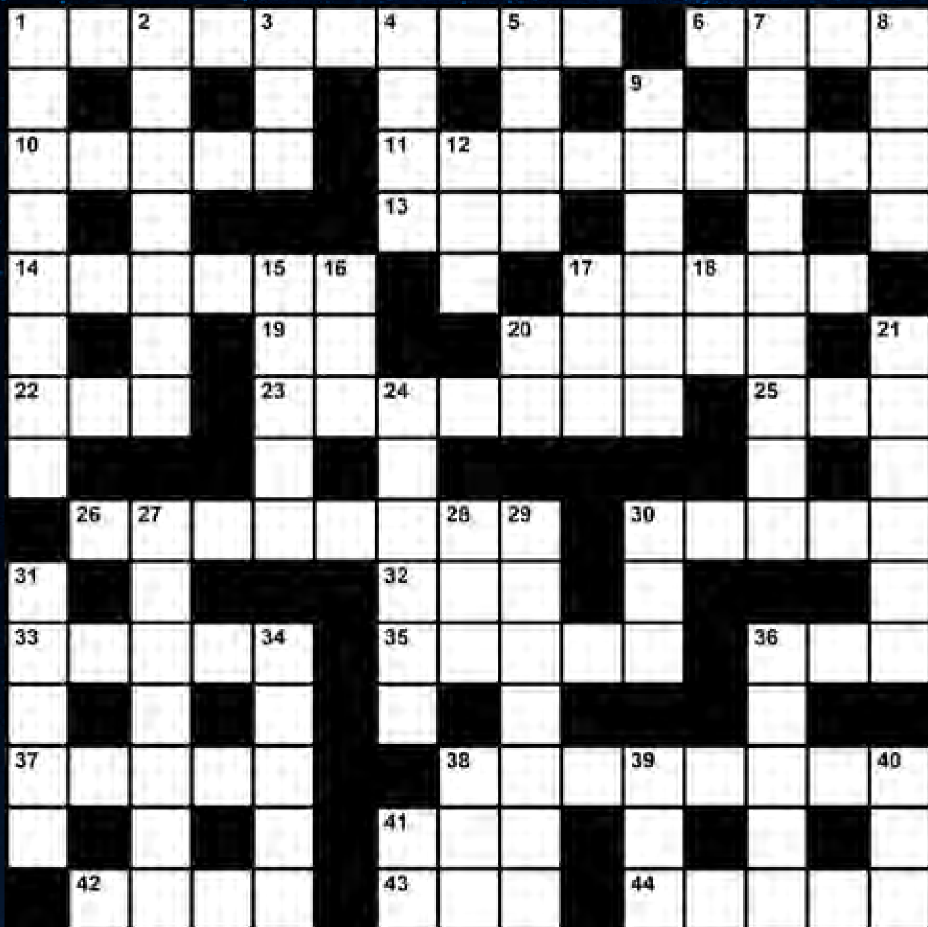
Valerie Neal, emerita curator in the Department of Space History at the Smithsonian's National Air and Space Museum, looks beyond Sally Ride to share the stories of 61 female astronauts over 45 years who have entered this male-dominated field. Neal interviewed many of these women to better understand their experiences. The book also includes 50 photographs.

The Giant Leap

PUBLISHED OCT. 21, 2025 (Basic Books)

Astrobiologist **Caleb Scharf** compares humankind's journey into space to other major leaps forward, including moving from the sea to land and from land to air. He considers this transition of society an evolutionary event, one that will bring both opportunities and risks. Scharf includes stories focused on the past, present and future of space travel.

Titles are meant to reflect a broad range of topics and are not reviewed or endorsed by Aerospace America or AIAA.



CROSSWORD

Test your knowledge then find the answers online.

Across

1 Newest branch of the U.S. armed forces, 2 words

6 This family of Cold War-era Soviet ballistic missiles was derived from the German V-2

10 In the sky

11 This cape has hosted the launch of many famous spacecraft

13 This term for an elite pilot originated in World War I

14 Stay in _______, kids

17 Last name of the actor who brought Mark Watney to life

19 How you might start a memo

20 Places where you could be stuck if your flight is delayed

22 Frank Rubio holds a NASA record for longest time aboard this

23 This Jupiter satellite sounds like one of the planet's moons, but it's not

25 Interstellar medium, abbr.

26 Astronauts and Michael Jackson might share a fondness for this move

30 The longest-operating crew transport design

32 Telescopes do this, in a manner of speaking

33 A specific slice of the atmosphere

35 How Europe enhances GNSS networks

36 "Yes, we ___"

37 Essential components for aircraft refueling

38 First name of Kelly Johnson's successor

41 Nasty guy, useful design software

42 "____ only" (confidential)

43 An aircraft has multiple of these compartments

44 The U.S. Space Force wants to demonstrate on-orbit refueling and other techniques with this small satellite series

Down

1 The Artemis III crew's ride to the lunar surface

2 This asteroid could get multiple visitors in the coming years, if plans hold

3 The electric aircraft developer that began as an Embraer division

4 This U.S. Navy drone is named after a marine animal

5 Wind ____: a giant sock if you didn't know the name

7 Mars rover exploring the Gale crater and Mount Sharp

8 Punctually

9 To navigate the air (verb)

12 To do something

15 This spacecraft could carry its first humans as soon as February

16 Nickname of one of the actors sounding the alarm in "Don't Look Up"

17 That, informally

18 __, myself and I

20 Plural of g-force

21 This company is developing delivery drones and satellite internet

24 Nickname for a satellite trying to catch a target

27 This orbiter has been searching for Martian water ice since 2001

28 The Odysseus lander broke one of these

29 Not the oldest NASA center, but perhaps the most famous

30 Scandinavian Airlines, abbr.

31 This small launcher had two explosions in 2025

34 The sun always does this in the east

36 Halley's, for one

38 Instead of an RFP, an agency might issue this

39 How you might say "plane" if you're in a hurry

40 Abbreviation of objects planetary defense experts are concerned about

41 Short-range radio communication system

The future of hypersonics research

Greg Scofield describes his 2022 return to Purdue University as "coming back home." That's understandable, given that he's spent most of the last decade there. Now, he sees mentoring the next generation of engineers as a large portion of his job leading Purdue Applied Research Institute's Hypersonics Lab. The lab specializes in assessing manufacturing techniques, as well as all kinds of hypersonic testing from thermo-mechanical to high-speed propulsion. It also focuses on building a workforce and completing test, manufacturing and design activities under contracts from industry and government. I chatted with Scofield about the lab's accomplishments so far and what's next. — *Marjorie Censer*

GREG SCOFIELD

Key Positions:
• Since 2024, director of Purdue Applied Research Institute's Hypersonics Laboratory. Since joining Purdue in 2022, Scofield has also served as a senior research engineer at the lab as well as deputy director.
• 2017-2022, materials engineer at Rolls-Royce.

Notable:
• The Hypersonics Laboratory is one of PARI's four laboratories. The other three are Infrastructure and Innovation, Microelectronics, and Energy and Energetics.
• The lab is based out of the Purdue Hypersonics and Applied Research Facility that opened in 2023. The roughly 6,000-square-meter facility is home to the HYPULSE reflected shock/expansion tunnel, the under-construction Mach 8 quiet tunnel and the Hypersonics Advanced Manufacturing Technology Center.

Age: 32

Resides: West Lafayette, Indiana

Education: Bachelor of Science in materials engineering from Purdue University (2016), Ph.D. in materials engineering from Purdue University (2021).

Q: What are the similarities and differences that you've seen switching gears from industry to academia?

A: There's a lot of similarities between industry and what we're doing with PARI. One of the things I love is we kind of split the difference between what academia does from a benchtop, laboratory scale — usually at the small scale — fundamental science and basic research, to full-scale production that I was used to on the industry side.

PARI gets to work in this cool middle ground where we're taking that early-phase discovery, those early TRL [technology readiness level] and MRL [manufacturing readiness level] discoveries and advancements, and move that up the chain to where we can transition it over to a large prime contractor or a large industry partner to be able to make, instead of ones and twos, hundreds to thousands of these. I love being able to work at the interface of academia and industry and government.

We get to train students on how to move technology through that development cycle. But the other neat thing about working in this environment is the fact that our students, our staff are prototyping full-scale systems. We've designed and built a scramjet that flew on the ground at the same flow conditions as the X-51. We're working with major primes in industry to scale up components that will eventually fly on systems.

Boeing built four expendable X-51A demonstrators for the U.S. Air Force, one of which flew for three and a half minutes under scramjet power in May 2013, the final flight of the program. — MC

We get to do a lot of the rapid prototyping. We get to advance the state of some of this early-phase technology to a place where it'll eventually affect our warfighters, our allies and partners as well. We're a little closer to the action when it comes to being able to work on real systems than you might be able to be purely on the academic side of things.

Q: It sounds like you might be later in that process than some labs, but earlier in the process than most industry research. Is that accurate?

A: That's pretty much spot on. Where we really sit in that development cycle is taking a technology that may work in the laboratory, in a controlled environment where you can get rid of some of the things that would happen out in the field and really understand at the basic physics, basic chemistry level. You can prove that concept in the laboratory scale. Where we sit is just a little bit past that, where now we're looking at what happens when we throw in an environment that would be more indicative of the real world.

A good example is some of our wind tunnel testing. On the early side of development, you're often doing modeling and simulation to look at how will a vehicle perform in flight, but it's difficult to model and simulate everything and get that accurately. We can take prototype models, physical models and actually put those into a large-scale wind tunnel or high-pulse wind tunnel and test those at Mach numbers ranging from Mach 4 all the way up to Mach 25 and beyond. There's not many places in the world that can do that, let alone in a university setting. We're able to test and build and design things at a scale that very few academic institutions have the capability of doing, but then we're able to continue to interface with industry in such a way that actually begins to affect the way they produce the next generation of their system or their vehicle.

Q: Is it challenging to find the projects that need the research work but that are relatively close to applicability?

A: It can be challenging in that everything at this scale doesn't always pan out. But that's the nature of research and development: that some things work well, some things don't work well, but you're continuously trying to understand why something doesn't work so you can inform your next round of testing and hypotheses.

In our case, for the most part, we're trying to partner with industry where they can bring their problems to us and we can help solve them. When we look at industry, research and development is really expensive. Internal research and development

> "When we talk about priorities, there's technological priorities and then there's economic priorities. You could have wonderful technology and never be able to field it and deploy it because it's too expensive."

dollars are prized. If you're a company, you want to know that when you take your IRAD [independent research and development] money and invest it in something, you're going to get the most bang for your buck. It's difficult for some companies, particularly small- and medium-scale companies, to have all of that depth of knowledge in-house.

That's where a place like Purdue, like PARI really can shine is we have this great bench of experts — faculty members across a variety of disciplines that all work interdisciplinary projects together — and we can take those faculty, those graduate students and staff and harness that intellectual capital that the university brings and apply it to a problem in industry. When they come to us and say, "Hey, we're having this trouble with this portion of a hypersonic vehicle" or something isn't going as planned, we can harness that intellectual expertise and drive forward a solution without them having to have that deep staff in-house.

Q: That's a great segue into how you set the lab's priorities. It sounds like that really is a conversation you're having with industry and government.

A: Absolutely. When we look at a new project that we want to start, there's certainly some areas where we say, "Hey, this is something that we believe we're leading in." We're doing a lot of ceramic printing, for instance, and I truly believe we're a national and global leader in that technology.

There's certainly other areas though where we're taking direction right from the warfighter, right from industry representatives and partners. A good example of this is metal additive for next-generation systems. We can print new geometries that we could never print before, and so we're looking at how do we create new alloys that we can use to further the capabilities of these systems. Same thing with lightweighting of systems for propulsion, and we've again done a lot of work in scramjets in our team and rely heavily on some of the Purdue faculty expertise there to be able to design new cooling technology for scramjets that ultimately comes from our partnership with industry. It's certainly from a priority standpoint walking hand in hand with our partners in industry and government to guide the work that we're doing.

Q: Is there some consistency to what those needs are?

A: Absolutely. When we look at the nation's priorities, it's a new hypersonic capability that's deployed that our warfighters can use. But cost is a massive driver there. When we talk about priorities, there's technological priorities and then there's economic priorities. You could have wonderful technology and never be able to field it

▲ Graduate student Adrian Flores operates an overhead crane to assemble HYPULSE's shock tube in preparation for a test.

PARI/Charles Jischke

"We're able to test and build and design things at a scale that very few academic institutions have the capability of doing, but then we're able to continue to interface with industry in such a way that actually begins to affect the way they produce the next generation of their system or their vehicle."

and deploy it because it's too expensive. That's a big problem our nation faces.

When we look at our priorities in terms of the projects that we've actively got going on within our facility, I'd struggle to think of one that doesn't have cost as a major driver. Whether it's government or industry, both are interested in how do we drive down the cost of manufacturing, validating and verifying and fielding these systems — and maintaining them, frankly, once they're fielded. Cost is that thread that connects all of our programs that we're working on. It's truly what's going to make the difference for the warfighter. If these systems are all exquisite and we can only produce a few of them at astronomical cost, we can never use them or we can't use them in numbers that matter.

Q: Beyond cost, can you describe another priority or two?

A: Working so closely with the Purdue workforce is a giant priority for us. President [Mung] Chiang's goal is to make Purdue the premier national defense university in the country. I think we're doing an absolutely great job of solidifying our place there through these massive investments in hypersonics and propulsion and in defense generally. With that comes being a university that's excited to work in the defense space. One of our big priorities as a hypersonics lab within PARI is creating pipelines of students that transition over to government, they transition over to industry, they transition over to academia in certain instances too, where they have hands-on experience with testing, with manufacturing, with design, with modeling and simulation of all of these next-generation hypersonic systems and even in some cases current systems that are being developed.

That's something that we hear time and again from industry and government: We need students coming out of these universities that want to work in defense, that have clearances. Our facilities and our projects enable us to clear students and move those students into industry with a secret, a top secret clearance. If you think, as a company, you want to bring on a student to support a classified program, it could be months to sometimes upward of a year where that new employee is sitting on the bench waiting for their clearance. That's something that we can begin to alleviate further upstream and begin to ensure that when those students enter the market or the industrial base, they're ready to go day one.

Q: Can you share a little bit about what you feel most proud that the lab has accomplished?

A: One of our biggest successes was the program that kicked off our hypersonics research and development at PARI. We had a contract through OSD ManTech [the Office of the Secretary of Defense's Manufacturing Technology Program] routed through the Naval Surface Warfare Center - Crane Division that ultimately was five projects within that program, all hypersonics related, that really kicked off our facility, the research that we were doing, getting students involved and developing a lot of the technology in our facility.

We did everything from scramjet design, build, test. The vision for that program was to help set up our facility that we're working in, which is our HARF facility — the Hypersonics and Applied Research Facility — and specifically the manufacturing space in that facility.

Within the HARF, we have the manufacturing center, which we call the HAMTC Center, the Hypersonics Advanced Manufacturing Technology Center. And then we have two hypersonic wind tunnels, the HYPULSE wind tunnel and the Mach 8 quiet wind tunnel, which is still under construction. HYPULSE is active; the HAMTC space is now fully active.

The vision for this space was we want to take our manufacturing, our testing, our design work and put it all in one place. Right now, if you look at how hypersonic vehicles are assembled and built and designed, it's often done in disparate locations across the country. Just the time it takes to go from a concept to a prototype to a test can be very long because it's not only coordinating teams, but you're taking a part, you're shipping it across the country to new machines; you're shipping it to another part of the country to be heat treated; you're taking it back to an assembly plant.

The vision here was vertical integration and specifically utilizing advanced manufacturing to enable that. We have a variety of additive manufacturing technologies. We have a variety of coatings and heat treatment technologies and testing capabilities all in one facility, as well as large-scale wind tunnels that are also within our facility. Ultimately, that enables us to go from a design to a fabricated prototype to a test all in a matter of weeks to months.

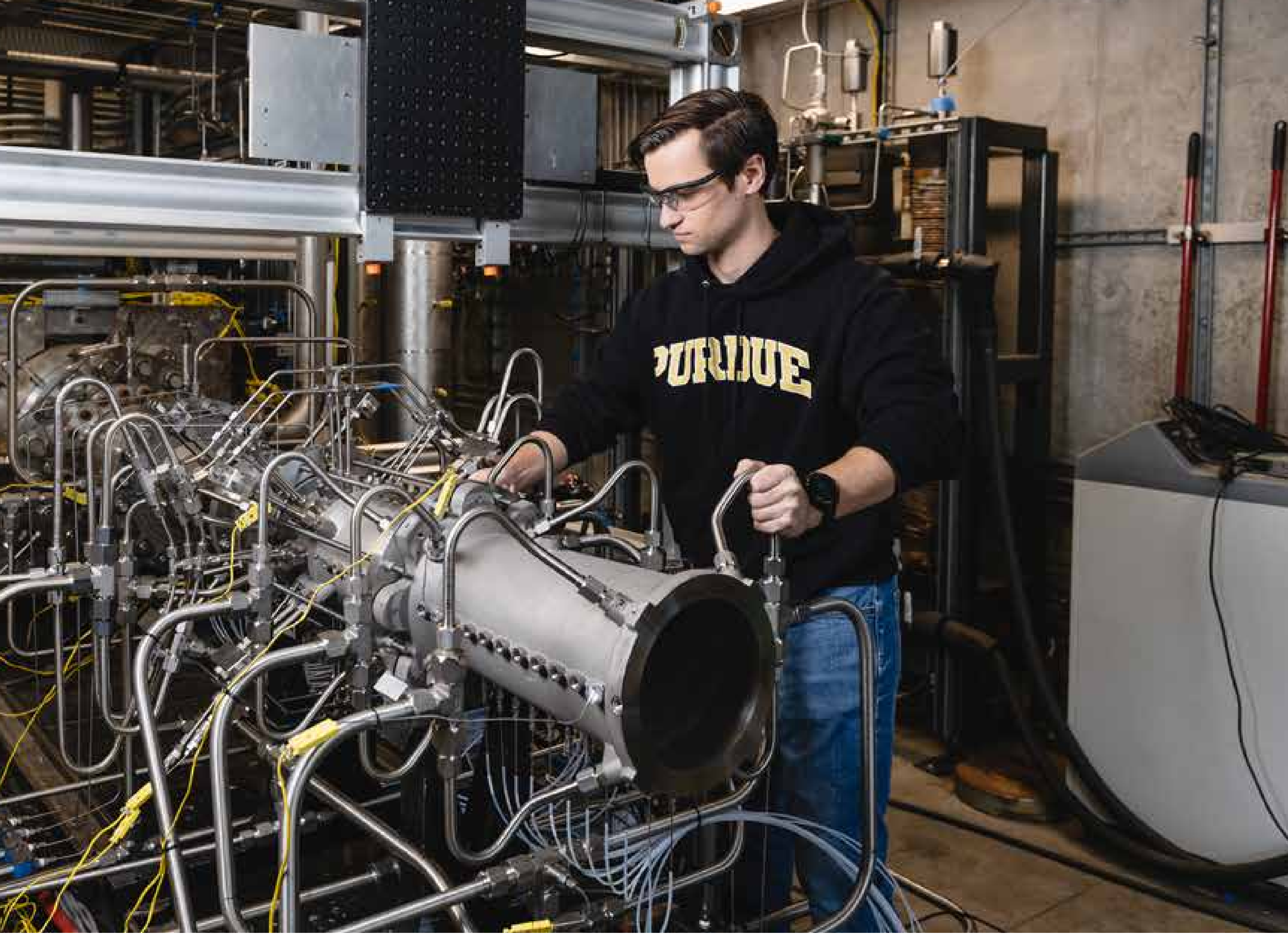
One of those projects that initially kicked off our contract with the Navy through OSD ManTech was a scramjet demonstrator. This thing was about 7 feet long, a couple feet in diameter. It was a large system — student-designed, student-built and then students tested it, all at PARI and Purdue. It took roughly 30 days on a printer to build that entire system. It had geometries that you couldn't traditionally manufacture. We flew it at the same flow conditions as the X-51 on the ground.

That's an example of the Navy and ManTech making an investment to stand up a facility that can increase our ability to rapidly prototype, it can increase our ability to demonstrate some of this technology quickly and then transition that over to companies to be able to take it and run with it into a production environment.

Q: How do you find or build the workforce that you need? It sounds like there's a cultural piece on campus that you think is important.

A: It's very easy at Purdue. The students here are excited. They care about national security and defense. There's a huge population here that has some personal connection to the military, to the defense industry, whether it's family members, themselves, friends that work in this space. So we don't have to do a tremendous amount of recruiting and pounding the pavement to find people who are interested.

We've set up structured programs to be able to create that pipeline of cleared workforce that's going to go into the defense industry. We've got what we call our PARI Scholars program, which is a partnership between PARI and the Engineering Undergraduate Research Office. One of the primary things we hear from industry is, "We love to be able to do research with you, but we're also after your students." When we hear that, we say, "Excellent, we can help you with that. What are some topic areas that you want us to tag students to and develop a workforce around?" Oftentimes, there's things in industry that aren't perfectly taught in classroom settings. We are able to take



▲ In 2024, a team of graduate students at the Purdue Applied Research Institute 3D-printed a full-scale scramjet roughly the size of the U.S. Air Force's X-51A Waverider. The students tested the engine at conditions it would experience when flying at Mach 5.

PARI/Charles Jischke

whatever that tradecraft might be, think of it almost like a capstone project and advertise through the PARI Scholars program directly to students.

Q: You're working closely with hypersonics on a regular basis. What do you think is the promise of that technology?

A: This is a technology that's here to stay. From a defensive capability standpoint, it provides options to the warfighter that enable deterrence and ideally prevent a Cold War from ever becoming hot. There are things that these vehicles can do that, frankly, make them very difficult to stop. From a deterrence perspective, that's a huge, huge advantage that it gives us compared to traditional ballistic missiles.

Long term, when we think of hypersonics, everyone likes to think of how cool would it be if I could travel from New York to Tokyo in just a couple hours. Eventually, there's applications for non-defense areas as well.

Q: What do you think is the biggest challenge? It sounds like it might be cost.

A: The cost of these systems is the real hurdle. We can develop fantastic technology. We can develop technology that lowers the cost of these systems, new materials, new algorithms, new microelectronics. But often it's the contracting process; it's the many steps that we have to move through to go from a design ultimately to a deployed system that drives that cost. If you're a large defense company, it's going to drive the size of your contracts department, it's going to drive the size of your legal department, it's going to drive the size of your finance department. We start stacking that on top of itself, and that drives up the cost of the vehicle beyond just the material cost. That's a huge issue.

There's the technological side too where we are working with very, very custom materials, one-off systems, systems that were designed as demonstrators that maybe didn't have mass production in mind. How do we go from we need a specialty material to be able to accomplish this mission to we can produce these by the truckload? There are industry providers out there that are capable of this. We have some of those pieces in place. It's just we need these systems to be designed with that in mind from the beginning to some extent. ★

ENGINEERING NOTEBOOK

From moon dust to moon colonies

Blue Origin is preparing for a demonstration this year of a suite of technologies that could provide the foundation for future self-sufficient lunar settlements. Paul Marks spoke to the lead technologist of the effort.

BY PAUL MARKS | paulmarksnews@protonmail.com

A rendering of the Blue Alchemist molten regolith electrolysis (MRE) reactor that Blue Origin is developing to convert moon dust into glass for solar panels and other materials required for self-sufficient lunar settlements. Blue Origin

In a sprawling laboratory complex in Los Angeles, researchers are developing technologies that could allow future lunar citizens to live off the land.

As Vlada Stamenkovic tells it, the instruction he and his colleagues received from their boss, Blue Origin founder Jeff Bezos, was a demanding one: “Show me that this is real, that it’s not just a dream.”

In other words, prove that it is possible to produce critical resources — breathable oxygen, rocket fuel and the metals and glass needed for solar panels and power cables — from nothing but moon dust.

“The idea of in-situ resource utilization was a kind of dream for many decades,” says Stamenkovic, senior director of the company’s Space Resources Center of Excellence in Los Angeles. “We have had to put our money where our mouth is and show that it works.”

There are now signs it’s beginning to. In September, Blue Alchemist, the company’s initial suite of eight lunar resource extraction technologies, passed a critical design review by NASA’s Space Technology Mission Directorate. NASA is involved because it has partly funded Blue Alchemist’s development with an award of $34.7 million.

“Making unlimited amounts of solar power, transmission cables and oxygen anywhere on the Moon supports both NASA’s lunar sustainability and Blue Origin’s commercial business objectives,” NASA says on its website.

That CDR milestone cleared Blue Origin to plan for a “full end-to-end autonomous terrestrial demonstration” of Blue Alchemist sometime in 2026, says Stamenkovic. This will involve engineers placing their regolith reactors and robotic manufacturing systems in what he calls “gigantic” vacuum chambers.

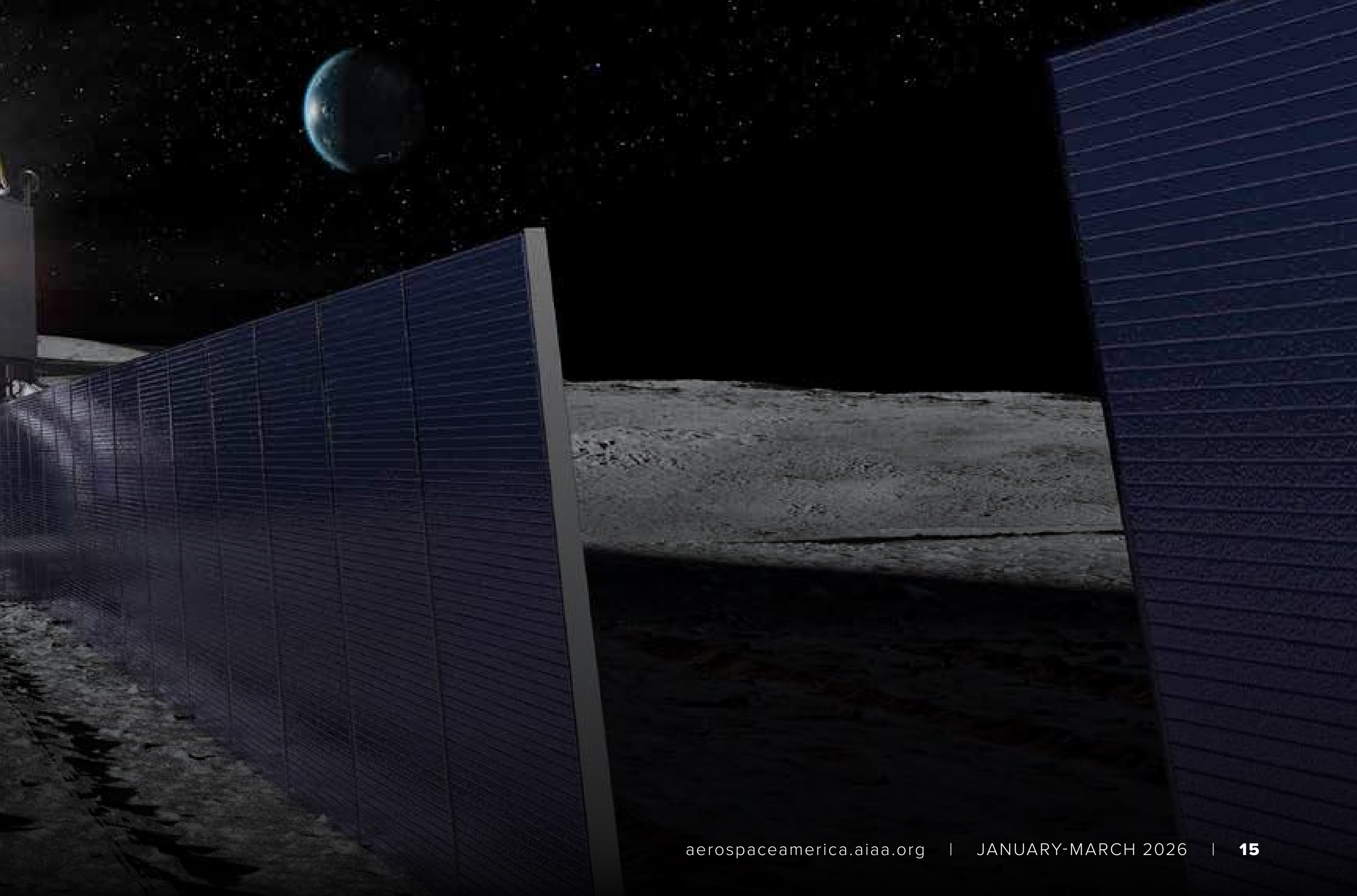
“We’ll put in different compositions of regolith simulants, and out of the other end will come a solar cell — and we won’t have touched anything,” Stamenkovic says.

If all goes as planned, Blue Alchemist will take moondust in and push out products like solar cells, cables, air and fuel — all in one-sixth of Earth’s gravity, in a vacuum, and on a celestial body with punishing temperatures fluctuating between 120 degrees and minus 133 degrees Celsius.

A multipronged puzzle

For this task, Stamenkovic has assembled a host of multidisciplinary experts in Blue’s Los Angeles facility. The sprawling three-acre (5,500-square-meter) lab is home to a 70-person team that includes geochemists, petrologists, mineralogists, planetary scientists, semiconductor specialists, materials scientists and metallurgists — plus electrical, mechanical, robotics and computer engineers. As for how to foster collaboration among people with such diverse technical backgrounds, he says the key has been

Paul Marks is a London journalist focused on technology, cybersecurity, aviation and spaceflight. A regular contributor to the BBC, New Scientist and The Economist, his current interests include electric aviation and innovation in new space.



focusing on the hard engineering problems that need solving for any moon settlement, rather than engaging in thought experiments over granular details like the size of a lunar colony and the designs of specific structures, from habitation modules to landing pads and data centers.

"I have stopped imagining and debating exactly what the vision looks like. There's not enough data, and it's all opinion anyway," says Stamenkovic. "Instead, we have asked ourselves what will we actually *need* to live on the moon."

One of the answers? A great deal of electric power. If lunar inhabitants are to be self-sufficient, they must extract their own water, breathable air, building materials, rocket fuels and the metal and glass needed for solar panels and cabling — from nothing but the rocks and regolith strewn around them.

For this reason, Blue Alchemist's primary aim is to develop solar power systems that allow each lunar settlement to stably generate at least 1 megawatt of solar-electric power from locally produced arrays spread across the moon's surface — almost seven times the power that the International Space Station's solar arrays have grown to generate in its quarter century on orbit.

A lunar resources extraction plant will need to be at least an order of magnitude more power hungry for good reason: "Chemical processing involves breaking chemical bonds, and there is a minimum energy you need to do that. You can't change it. So to sustain chemical processing on the moon, we need to get in the order of a megawatt to have an effect. That's the scale we've decided on for stable power generation if we're not to operate there in a pure survival mode," says Stamenkovic. Long term, he'd like it to scale to a gigawatt.

The "chemical" at issue here is lunar regolith, an aggregate made of rock that's been crushed over billions of years by relentless meteoroid and micrometeoroid impacts, and from bombardment by charged particles like protons in the solar wind and galactic cosmic rays. "Chemically and mineralogically, lunar rock is very similar to many Earth rocks and has a similar formation origin," Stamenkovic says.

Like on Earth, the composition of a given sample of regolith depends on where it comes from. Take the moon's once-volcanic mare regions, like the Sea of Tranquility that Apollo 11 landed in. There, the rock comprises largely silicon, iron and magnesium chemically bound to oxygen. In the highlands and south pole, the rock has a greater proportion of aluminum and calcium bonded to oxygen.

And 45% of the mass of the rock in both regions is oxygen, so Blue Origin is aiming to break that oxygen free from the other compounds and collect it as a propellant or for breathing. The liberated silicon and iron can then be turned into solar cells, the calcium and aluminum into power cable or solar panel conductors. (Although calcium oxidizes immediately on Earth, in the lunar vacuum it can't, and it's a great conductor.)

A great big melting pot

But how to perform this extraction? On Earth, feedstocks including coal and natural gas, plus a whole lot of water, have been heavily used in thermally driven processes to extract metals from rock ores. But as the whole idea here is to avoid feedstocks expensively launched from Earth, Blue Origin has — after what the company says was a thorough consultation with independent geochemists — opted for a lunar surface resource extraction approach using only in-situ energy, one called molten regolith electrolysis (MRE).

"In space, you do not want to rely on chemical processing methods requiring huge amounts of liquids or gases," Stamenkovic says.

Instead, Blue Alchemist's MRE reactor would use electricity from surface solar arrays to heat crushed regolith powder to 1,600 C, creating a melt that is thermally and electrically conductive. Electrodes would then pass a current through the melt, which has the effect of separating metal and silicon ions from the oxygen ions they were bound to. The positive metal and silicon ions migrate to one electrode and the negative oxygen ions to the other, where the gas bubbles off for collection as propellant or breathable air. To ensure it actually is breathable, Blue

>> STORY CONTINUES ON PAGE 18

Blue Alchemist's products

By melting moon dust in a reactor at 1,600 degrees Celsius, surface crews would be able to "tap off" a variety of important resources at different electrode voltages in a molten regolith electrolysis system. These include:

- Breathable oxygen for life support
- Propellant-grade oxygen for rocket fuel
- Glass (silicon dioxide) for solar panel covers and habitat windows
- Silicon for solar panel semiconductor substrates
- Aluminum for solar panel structures and power cables
- Iron for building settlement structures
- Magnesium, calcium and titanium, among other metals
- Solidified bricks for constructing habitats

Blue Origin

Twin prospector satellites will seek out hydrogen, helium-3, platinum and rare earth metals

Because all lunar regolith is oxygen rich, Blue Alchemist installations on the moon could produce oxygen for rocket propellant from almost anywhere on the surface. However, that is not the case for that other popular rocket propellant: hydrogen. Lunar hydrogen is more scarce, locked up either in water ice in the moon's permanently shadowed regions, or in the form of hydroxyl groups inside hard-to-find minerals.

So, any spacefaring organization had better place its insitu resource extraction plants near hydrogen deposits — but how to find them? Enter Oasis-1 and Oasis-2, the pair of low-polar-orbiting prospector satellites that Blue Origin announced in September. The company is developing these alongside the Luxembourg Space Agency, the European Space Resources Innovation Centre and GOMspace, a Denmark-based smallsat platform maker.

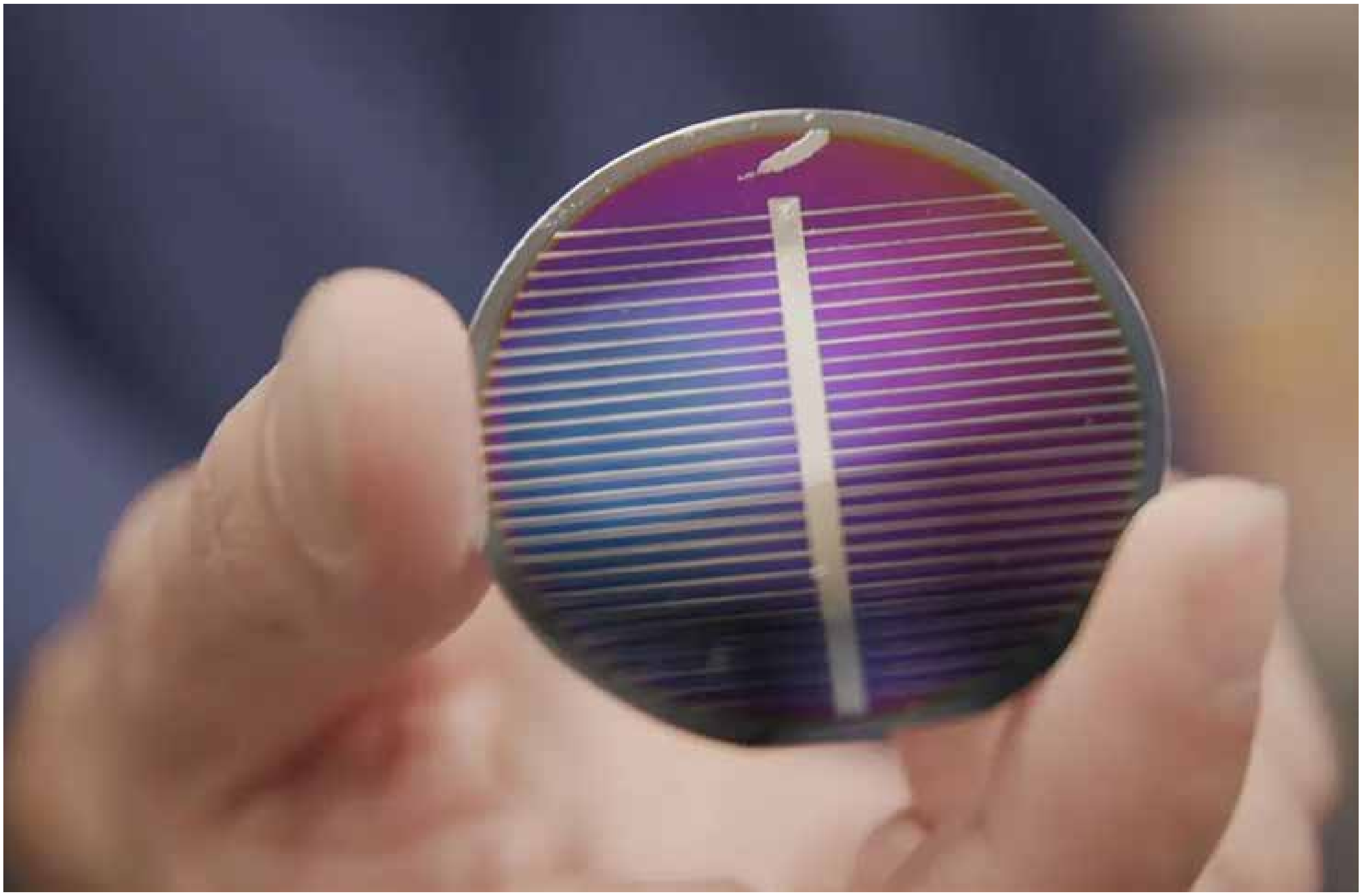
The Oasis spacecraft are to be sent to lunar orbit sometime in 2026, following the launch of the company's Blue Moon Mk 1 uncrewed lander that is scheduled for early this year.

"Oasis will launch on a later mission following that first landing because we need some data from that landing," says Vlada Stamenkovic, senior director for Blue Origin's space resources program in Los Angeles. "But we're working heavily on Oasis already, so this is all in the very near term."

The twin craft are each to be equipped with a spectrometer that can sense the neutrons produced in collisions between galactic cosmic rays and the lunar surface, down to a depth of 1 meter. Hydrogen has a telltale neutron signature, so mission planners hope that the spacecraft will be able to find and map large deposits of water ice or hydroxyl-group-containing minerals. "The search for hydrogen is the primary mission of Oasis, but we're also going to look for evidence for helium-3, precious metals — specifically platinum-rich metals — and rare earth elements," says Stamenkovic. "We really want to understand the full inventory of resource possibilities on the moon."

Helium-3 may have applications in advanced quantum computers and in putative fusion reactors, but it is the hydrogen that will be the real prize, says Stamenkovic, so rocket fuel doesn't need to be shipped to the moon, at great expense, from Earth.

"We really care about the hydrogen," he says, "because the heaviest thing in spaceflight is propellant." — *Paul Marks*



Origin is using flight metrology hardware from NASA's Kennedy Space Center to assess the purity of the oxygen it extracts. If it's tainted, a purification technology developed at Johnson Space Center can clean it up.

Stamenkovic thinks contaminated resources will be unlikely because Blue Origin designed the MRE reactor to have precision control over what is extracted at any one time. "The voltage across the electrodes corresponds to the energies that you require to break bonds. So by adjusting that voltage, we can separate specific metals and tap them off one by one. We start with iron, then the next stage is silicon, and then aluminum — and as a by-product, we get glasses," he says.

That glass is vital for the longevity of the settlement's megawatt-scale solar power arrays. Without glass to cover them, the heavy solar radiation flux would destroy the panels "in a few tens of days," according to the company's calculations.

Simulate to gravitate

As all the company's lab experiments must take place under Earth's gravity, Blue is heavily relying on computational fluid dynamics (CFD) simulations to verify that the Blue Alchemist tech will work in the one-sixth g lunar environment.

"Lunar regolith is definitely going to be full of surprises," says Stamenkovic. "One of the biggest risks is if there are differences in lunar gravity on different parts of the moon, how do we mitigate that?"

His team's answer has been to simulate its way out of any such trouble by varying the geometry and dimensions of the reactor vessel CFD model in multiple ways, and simulating different shapes of electrode — such as star- and U-shaped ones — to adjust current density, the parameter that controls the speed of metal, silicon or oxygen production. Stamenkovic says the team is now confident it has optimized Blue Alchemist against any lunar gravity variation issues.

Is the team also confident, I asked, that the regolith simulant melting in their reactor is representative of what pioneering users will one day shovel into it on the moon? Having NASA as a partner helps here, Stamenkovic says, as Blue Origin has been able to compare the various regolith simulant compositions it tests with genuine regolith brought back from the Apollo landing sites.

"Although NASA only allows us a very little regolith to compare ours with, it's a material that's been so well studied we're sure that our system will be able to handle all kinds of regolith," says Stamenkovic.

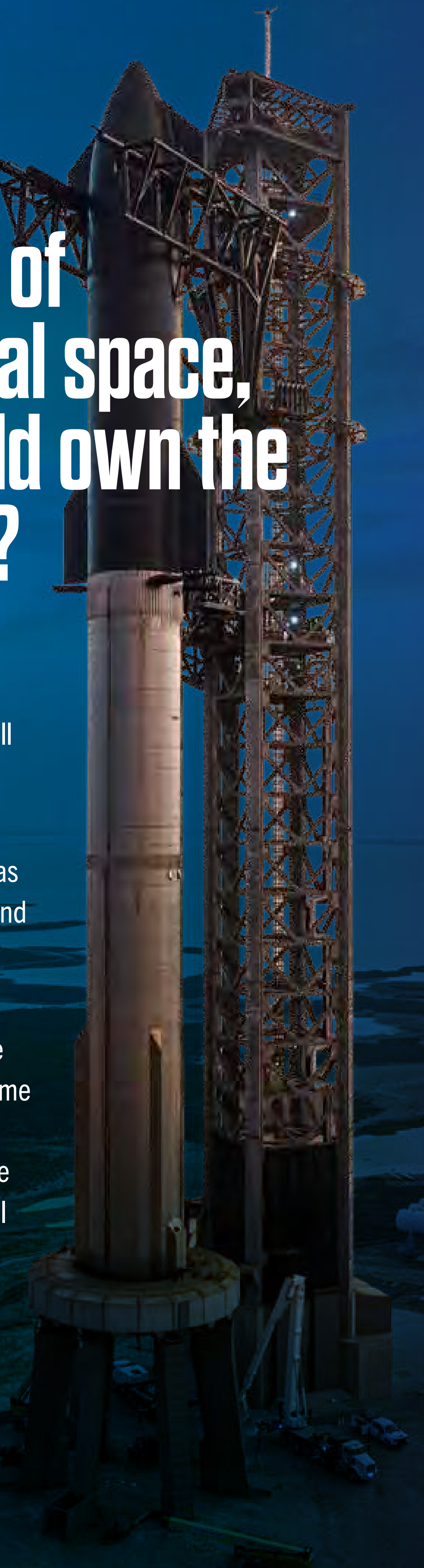
"We can now build a system that's going to go to the moon to make oxygen for astronauts, for fuel cells, and for propellant." ★

▲ Blue Origin created this functioning solar cell prototype in 2023 from lunar regolith simulants.

Blue Origin

THE BIG QUESTION

In the age of commercial space, who should own the hardware?



For most of its history, NASA hired companies to build hardware like the Saturn V rocket and the Apollo spacecraft. NASA then took full ownership of those vehicles.

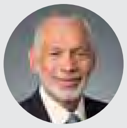
Today, the agency is increasingly shifting toward purchasing services, not hardware, from its contractors. Since 2014, for instance, NASA has awarded SpaceX nearly $5 billion in contracts to ferry astronauts to and from the International Space Station.

These changing roles raise many questions, particularly around the ownership of and responsibility for space hardware. Can NASA ensure the reliability of spacecraft developed for services contracts in the same way it does for spacecraft it owns? Will private companies preserve history-making spacecraft in the same way NASA did with much of the Apollo hardware, transferring ownership to the Smithsonian's National Air and Space Museum?

I reached out to five experts and asked them: In light of the rapidly growing role of commercial space companies, who should own the hardware, both during missions and after? — *Jon Kelvey*

Charles F. Bolden Jr.

NASA administrator 2009-2017; former astronaut and retired U.S. Marine Corps major general.



With few exceptions, I'm a firm believer that contractors should own and operate hardware, not NASA. Our vendors, like Rockwell and Boeing, built our rockets and vehicles, and then we purchased, owned and operated them. And that's where the problem came in. On top of spending a lot of money getting it built and delivered, owning and operating costs a lot of money.

During the Obama administration, many of us at NASA decided there was no longer a need for NASA to spend the money to own rockets and airplanes. With capable commercial operators, we could transition to public-private partnerships and purchase services from them, not hardware. That's the model NASA uses today for human spaceflight and cargo to the ISS through the Commercial Crew and Cargo programs, and I think that's the model we should be following for almost everything, including things like Earth-observing satellites.

There are some exceptions. Certain exquisite science or intelligence satellites may be more appropriate for the government to own and operate. I doubt there's a company that wants to own something like the James Webb or Hubble space telescopes, though I could be wrong.

By transitioning to purchasing services instead of hardware, NASA not only saves money on overhead and maintenance, but we also reapportion risk. Let me give you the Boeing CST-100 Starliner as an example.

Today, with NASA procuring services, we exercise a safety model that we call "insight," wherein we embed personnel into the contractor's facilities at their request to offer advice and our insights into safety requirements, instead of the traditional oversight in which NASA dictated everything from design to manufacturing to the contractor. We tell the company what we want and offer our services as consultants and advisers on the project, but we're not constantly looking over their shoulder. We probably should have been exercising the same amount of insight at Boeing that we were at SpaceX, and it's my belief as the NASA administrator at the time that we didn't do that. And so we experienced the delays and in-flight failures on Boeing's first Orbital Flight Test (OFT-1) in the Starliner program.

But I would vehemently disagree with somebody who says it didn't work out. It worked out exactly the way NASA should want it to, where the contractor, who owns and operates the vehicle, has taken responsibility for analyzing and repairing and resolving any problems. It's a firm fixed-price contract.

The one area where NASA's move to purchasing services introduces uncertainty is the historical preservation of spacecraft and artifacts. NASA and the Smithsonian Air and Space Museum signed an agreement in 1967 that made the museum into the equivalent of the National Archives for historic NASA hardware. But it's not clear how that process works when NASA doesn't own the artifact. To my knowledge, the Smithsonian does not yet have a Falcon 9 or a SpaceX Dragon because the vehicles belong to SpaceX, not NASA. *[SpaceX in 2022 donated a Merlin engine and Falcon grid fin to the Smithsonian, but NASA was not involved in that transfer. — JK]*

One possible solution would be to stipulate in the service contract that ownership of the first vehicle flown on an operational mission for NASA will transfer to NASA. Then, NASA can transfer the vehicle to the Smithsonian as we always have. Commercial operators can decide if that contract works for them, just as they do with fixed-price contracts.

"By transitioning to purchasing services instead of hardware, NASA not only saves money on overhead and maintenance, but we also reapportion risk."

Mike Gold

President of civil and international space business for Redwire; former NASA associate administrator for space policy and partnerships.

The answer is yes — both. When it comes to achieving national priorities in space, it should never be a question of the private sector or the government, but both the public and private sectors. Public-private partnerships are absolutely vital to maintaining American leadership in space.

We have to be very cautious of one-size-fits-all statements, and so I fundamentally disagree with the nature of the question. A better question is, what are the best roles of government and the private sector in accomplishing specific missions?

When you're dealing with a mission that has new, untested technology or one that lacks a clear return on investment, then you've got a strong case for government ownership and operation. For example, in the early days of space development, there were only a half dozen or so satellites, and they were all constructed, owned, and operated by the government. But, as private sector capabilities increased and an orbital economy emerged, the government's role shrank proportionately.

That to me is the ideal cadence of public and private sector coordination in space. As the private sector matures to reliably deliver a capability, the government should turn those capabilities over to the private sector and move on to more ambitious programs that don't yet have a return on investment. The government's role should always be to push the envelope of what is possible. NASA should focus on returning to the moon with Artemis, and then move onward to Mars, rather than on owning and operating spacecraft for taking astronauts to and from low-Earth orbit.

This goes beyond freeing NASA's budget and attention for more ambitious exploration and science missions. If you look at the international field of play, we are in an existential competition with China over the moon: Whoever reaches the moon first to establish a permanent foothold will establish the rules of the road in space. They will, in turn, wield influence over everything from trade to national security alliances terrestrially. Whoever controls the moon will eventually control the Earth.

The American private sector is our greatest tool in that competition, the best arrow in the quiver to defeat the Chinese. Inevitably, China will eventually spend more than we do on space, so we must out-entrepreneur the Chinese. And that means leveraging our entrepreneurial spirit that created the second golden age of space, harnessing the capabilities of private sector companies.

But there is also a strong role for government, in that the SLS and Orion may represent our best chance of beating China to the moon quickly.

So, beware of false dichotomies. It's not LEO or lunar; it's LEO and lunar. It's not public or private; it's public-private partnerships attuned to the requirements of specific missions. That's how we create the business cases, the capabilities and the international partnerships that will support missions in LEO, on the moon and beyond. It has to be an all-of-the-above approach for America to win the future.

"A better question is, what are the best roles of government and the private sector in accomplishing specific missions?"

Christopher Johnson

Senior director of legal affairs and space law at the Secure World Foundation, a Colorado-based nonprofit.

From the perspective of international space law, it doesn't matter who owns the hardware. Because at least one government, possibly multiple governments, will always be responsible for that hardware and the actions of the people operating it.

From NASA's perspective, the move toward purchasing services rather than spacecraft could be a shrewd one. In my interactions with folks at NASA, I've always found that what they want most is to do science and exploration. If SpaceX owning and operating a spacecraft is more economically efficient and gets NASA astronauts back on the moon doing science, then so be it. And if the U.S. government owning the spacecraft gets them to the moon, then so be it.

It may come down to the specific mission and purpose: The U.S. government owns military aircraft used for missions, but military personnel often fly commercial airlines to their posts because it is economically efficient.

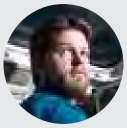
Under international law, the foundation of which is the 1967 Outer Space Treaty, it doesn't matter who owns the spacecraft. NASA owning and operating a spacecraft, SpaceX owning and operating a spacecraft for NASA, and Blue Origin owning and operating a spacecraft for its own purposes are all allowed under international law. But the U.S. government is equally answerable for all of the activities of each of those missions. Meaning, if they do something wrong, we are responsible for it, just like a parent may be responsible for the activities of their child. If any of those spacecraft or operators cause harmful damage to the space domain or fail to show due regard to other actors in space or fail to treat astronauts as envoys of mankind, which are obligations under the Outer Space Treaty, then the U.S. government is responsible for the legal and political consequences and repercussions of those wrongful acts.

This new space age of private actors doing really bold, ambitious, novel, unique and pioneering things in space doesn't in any way threaten the international rules, but it will test the extent and the understanding of those rules. The next 10 to 20 years are really going to flesh out all the particularities and nuances of international space law. But I don't think there is an overriding reason of national prestige that demands the spacecraft that next delivers American astronauts to the moon be a U.S. government spacecraft. However they get there, and whoever owns the spacecraft, the headline is going to be "America lands on the moon."

"The next 10 to 20 years are really going to flesh out all the particularities and nuances of international space law."

Geoff Nunn

Adjunct curator for space history at the Museum of Flight in Seattle.



I can see the pros and cons of either the traditional structure of NASA owning and operating spacecraft or the newer commercial structure.

As a historian, I can say the commercial structure presents new challenges for the preservation of historic space artifacts. But the question of who should own and preserve hardware produced by the space program is not a new one. There were discussions within the U.S. government during the Apollo program, for instance, because at first there were no provisions for the historic preservation of the spacecraft after they completed their missions.

NASA hung onto its early spacecraft at first, recognizing their historic significance, and hired its first chief historian, Eugene Emme, shortly after the agency formed. They quickly realized NASA needed to focus on making, rather than preserving, history and worked with the Smithsonian, which was then amending the title of the National Air Museum to become the National Air and Space Museum. They entered into what was called the NASA-NASM Agreement, which says any historic hardware from NASA gets transferred to the Smithsonian following its useful life or its mission.

A lot of historians across the country are wrestling with the question of what historic preservation looks like at this moment. We are making space history right now, and not only is private ownership of the hardware challenging, but the number of actors making that history is also challenging. It's much more difficult to come up with a singular agreement like that between NASA and NASM to solve for everything.

Some of the private companies recognize the history that they're making and have taken some independent initiative to preserve it. Blue Origin donated to the National Air and Space Museum its first New Shepard capsule that carried people. And SpaceX has donated some of its Cargo Dragon capsules to institutions like the Griffin Museum of Science and Industry in Chicago (though we don't yet have a Dragon at the Museum of Flight). I would also hope that the first Starship to land on the moon and return would be preserved.

But that brings another emerging challenge for space history preservation: Starship is gigantic. What museum could have room to display it? There are only three Saturn V rockets still in existence: one at Kennedy Space Center, one outside Johnson Space Center and one at the U.S. Space and Rocket Center in Huntsville, Alabama. They basically require a building the size of a shopping mall to fit them. If Starship is the shape of historic space missions to come, we're going to have major logistics challenges on top of sorting transfers of ownership.

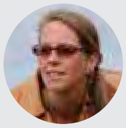
Since 2018, I've been part of a project called To Boldly Preserve. We're a collection of historians and museum curators who are trying to answer some of these questions. How do we ensure we don't lose any of the important history being made today without overwhelming everyone involved? The discussions are ongoing, but one thing we all recognize more and more is that, absent a process, history does not preserve itself.

"If Starship is the shape of historic space missions to come, we're going to have major logistics challenges on top of sorting transfers of ownership."

"If you want to ensure space history is preserved, you have to think deeply about this because there are no clear "safe" universal solutions — we have to evaluate everything on a case-by-case basis."

Rachel Tillman

Aerospace historian and founder of the Viking Mars Missions Education and Preservation Project nonprofit.



I look at this from the perspective of the reclamation and preservation of space artifacts. The question of ownership is always the first question, and it is a complex one that requires analysis.

Ownership of an artifact can change over its lifetime and is squishy to begin with since a spacecraft may have hardware contributed by multiple entities. If you want to ensure space history is preserved, you have to think deeply about this because there are no clear "safe" universal solutions — we have to evaluate everything on a case-by-case basis.

Private space companies may preserve their own artifacts, but will they make them publicly accessible? Museums like the Smithsonian make artifacts available to everyone because they are free, but many museums are not easily accessible due to entry fees. Further, most museums and archives also throw away or sell 30-70% of everything donated to them. They call it deaccession.

My father [James Tillman] and I took legal ownership of the only flight-qualified spare Viking Lander and associated hardware in the 1970s after NASA deaccessioned them. I also ensured my father's work was preserved throughout his life and after, as I understood its value to education, history and humanity. Those items are privately owned by me, precisely so they will not be thrown away or sold, even after I pass.

Because I knew many people associated with the Viking missions were throwing away their old materials, I founded my nonprofit to preserve the oral histories, archives and artifacts. I believe it's important to protect the aggregate of mission materials, which includes my privately owned materials and everything donated to the nonprofit. I preserve and maintain the Viking Archive in its entirety, which includes both, because together they are better protected than separately.

At the same time, I'm very much against historic artifacts being in private hands unless the owners have an appropriate trust similar to what I created to ensure those items are preserved upon their death. In July, Congress passed a bill ordering the Smithsonian to transfer ownership of the space shuttle Discovery back to NASA for relocation to Texas. *[President Donald Trump's sprawling tax-and-spending law allocated $85 million for the transfer. — JK]* But the Smithsonian owns Discovery just as I own the Viking Lander flight spare, although my interest is protected even more because it's privately owned.

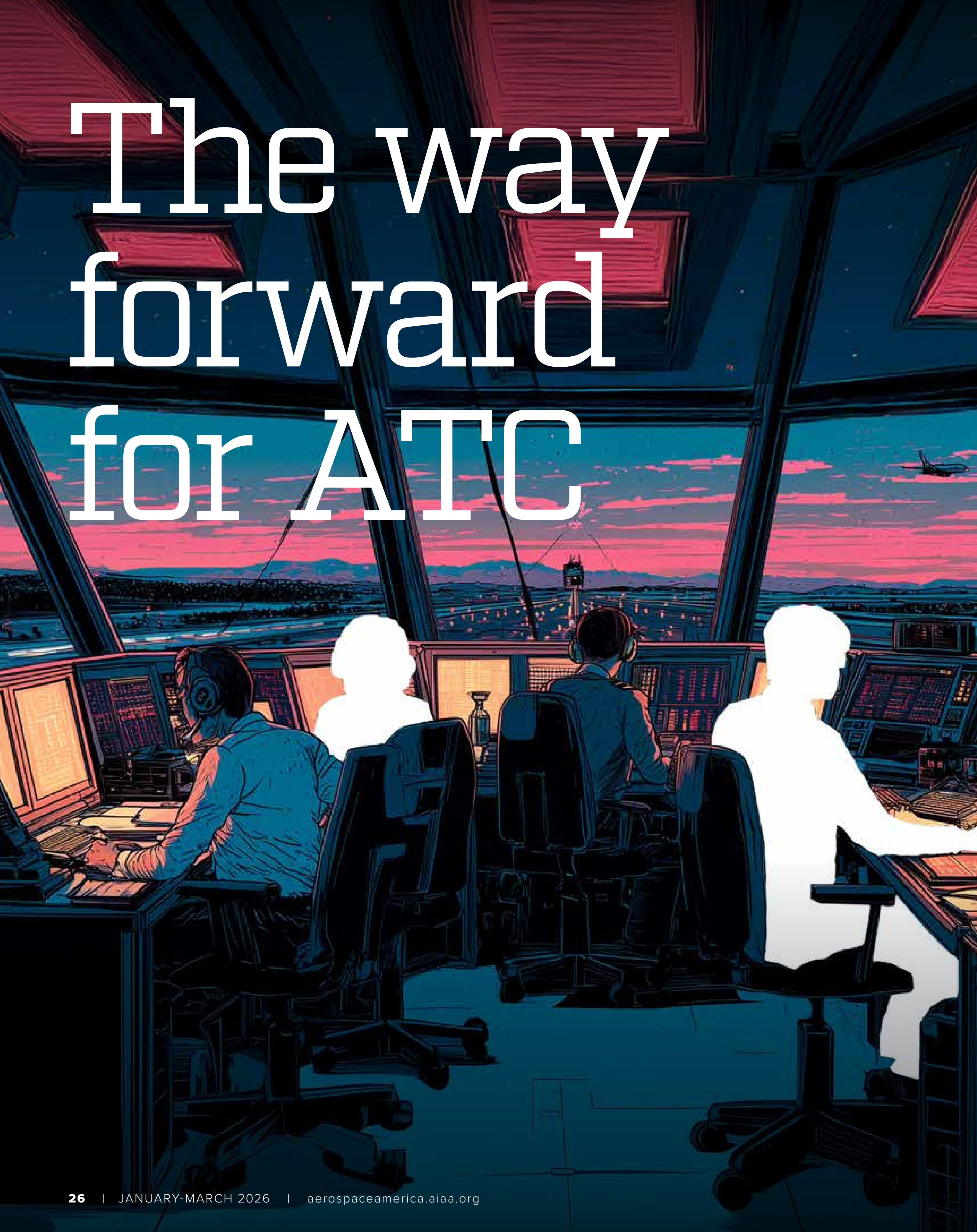
And those are just the kinds of issues around artifacts on the ground. What about preserving historic satellites in orbit, like Vanguard 1? Or the descent stage of the Apollo 11 lunar lander on the moon?

To help facilitate responsible discussion around these questions, I've created a framework for analyzing any proposed item for reclamation or preservation, whether it's on Earth, in orbit or on another celestial body. I've invited other historians, curators and academics to weigh in and help develop this framework as a way to identify artifact ownership, the responsibilities of owners, liability and a chain of custody to change ownership for artifacts. It begins with assessing who the stakeholders are: the manufacturers that made it, the space agencies that used it and the people of the nation who created and used it.

Then we ask who owns the artifact now, and how ownership and liability can be transferred. We also have to assess the risks of transferring ownership or moving an artifact — for instance, attempting to capture Vanguard could cause it to deorbit or strike something else — against the value of preserving that artifact in specific ways and places. Some items, such as Mars samples, might be best preserved on private space stations for planetary protection purposes, for example.

This framework is just the beginning of a discussion about what a process for responsible preservation of space history would look like. Whatever shape it takes, it must be a global process, not one led by me or a handful of historians or the U.S. government, or even a singular special interest group like archaeologists or consortia. Because at the end of the day, these things truly belong to all of us. And we need to protect our history as if it belongs to everyone. ★

The way forward for ATC



Last year's fatal midair collision outside Washington, D.C., and 43-day government shutdown put a spotlight on the strained U.S. air traffic control system. As the Department of Transportation and FAA proceed with plans to grow the workforce and overhaul equipment, Charlotte Ryan explores what brought ATC to this point and the challenges ahead.

BY CHARLOTTE RYAN | charlotte-ryan1@hotmail.co.uk

On a cold January evening at Washington's Reagan National Airport, an air traffic controller's voice cut through the noise of a conflict alert: "PAT two-five, do you have that C-R-J in sight?"

The controller was speaking to the three U.S. Army personnel aboard a Black Hawk helicopter, flying near the airport for a routine training flight. Seconds later, as the rapid beeping in the background continued, the controller directed, "PAT two-five, pass behind that C-R-J."

The helicopter pilot requested to keep visual separation from the incoming Bombardier CRJ700 jet, or monitor it manually, which the controller granted.

Inside the Black Hawk, the Army instructor asked the pilot to "Come left for me, ma'am," an apparent attempt to steer clear of the jet. Seconds later, the beeping accelerated, and the controller heard a surprised reaction from the jet.

Then silence.

These were the final moments before the collision near Washington, D.C., that sent both craft plunging into the Potomac River, killing all 67 aboard. It was the first major commercial plane crash in the U.S. since 2009, and the deadliest since 2001.

The National Transportation Safety Board's final report of the accident is expected in January. The preliminary report published last March and public meetings held throughout 2025 indicate that among the contributing factors was a controller staff stretched too thin to manage the airport's traffic. Specifically, air traffic controllers told investigators that their pleas to reduce traffic, change a route that put helicopters into the path of aircraft and have more staff assigned to the tower had all been ignored.

It was a tragic illustration of what industry groups and experts have been warning for years: The U.S. air traffic control system is overstretched and understaffed, to the point that minor equipment glitches or weather disruptions can cascade into major delays or even safety risks.

The Potomac crash "is an example that the aviation system as a whole failed that evening, and we owe the families and friends of those victims our best effort to make sure the system is better, safer and stronger," says Tim Arel, the former head of FAA's Air Traffic Organization, in an interview. He took a buyout offered by the Trump administration in April, capping a nearly 40-year career at FAA.

Since the January collision, FAA has made a number of changes aimed at making operations around Reagan Airport safer, an FAA spokesman told me in an emailed statement. These include eliminating the use of visual separation within 5 miles of the airport and increased support, oversight and staffing.

Charlotte Ryan is a London-based freelance journalist who previously covered the aerospace industry for Bloomberg News.

"Safety remains the FAA's highest priority," the spokesman said. "We are closely supporting the NTSB-led investigation, and we will quickly take any necessary actions and conduct appropriate reviews based on the evidence."

Even in non-fatal incidents, controllers are reporting challenges with equipment and operations, according to my review of controller reports of 2025 incidents at busy airports, published in a NASA safety database. Communication failure is "a grave threat to safe operations" at Newark Liberty International Airport, reads one report, which goes on to warn that "a midair collision is imminent." Another report out of Atlanta calls for authorities to "fix the frequencies before something bad happens." A third from Fort Worth, Texas, reads that the airspace around the airport is "so out of control, so unsafe" due to aircraft that fly using visual navigation.

"In light of DCA, it is disgusting that this is still Class E airspace," the Fort Worth controller wrote, referring to the Potomac crash. Helicopters and other aircraft that operate under Visual Flight Rules aren't required to be in contact with ATC as they approach, making it potentially trickier for controllers to manage traffic.

Several reports mention controllers juggling training and directing aircraft, and others mention problems with transmission.

Amid mounting pressure for FAA to address all of these issues, Transportation Secretary Sean Duffy in May laid out a plan to overhaul ATC, and in early December announced that Virginia-based contractor Peraton would serve as "prime integrator" of the rollout. The initiative is to be partially funded by $12.5 billion included in President Donald Trump's signature legislative package.

"The system we have here is not worth saving," Duffy said in May. "I don't need to preserve any of this; it's too old."

Increase hiring

Central to any plan to address air traffic woes is hiring more controllers.

"We haven't had enough air traffic controllers in America for a very long time," Duffy said in the aftermath of the DCA crash. "They are stressed out. They're tapped out. They're overworked. That's no excuse. It's just a reality of what we have in the system."

Today, there's a shortage of about 3,800 controllers, according to NATCA, the National Air Traffic Controllers Association. Such shortages date back to 1981, when President Ronald Reagan fired some 11,000 controllers in one fell swoop after they refused to return to work from a strike.

FAA hired thousands of controllers in the following years, but many of them are now reaching retirement age. The total workforce for fiscal 2024 was 14,264 air traffic controllers, and 6,872 are projected to depart through 2028, according to FAA's workforce plan published in August.

▲ In addition to overhauling the entire ATC system, FAA is implementing additional tools to help reduce runway incursions and close calls. The air traffic control tower at Centennial Airport in Colorado, pictured here, was the first to receive Runway Incursion Devices that use red and green lights to indicate whether runways or taxiways are occupied, FAA announced in March.

FAA

▲ U.S. Transportation Secretary Sean Duffy in May announced FAA would overhaul the air traffic control system.

FAA

To offset this, the agency plans to hire "at least 8,900 new air traffic controllers through 2028," the report reads, but hurdles remain there as well. There's a stubbornly high dropout rate during training — overall failure rates reached 26% in 2024, with even higher rates at more congested facilities.

According to former controller Rob Mark, who now runs the aviation blog Jetwhine, it's a demanding job. The long hours are "a killer," and not everyone can handle the pressure involved in directing traffic in busy airspace.

The rigid hierarchy and red tape can also prove challenging.

"It's still very much bureaucratic, and I don't think a bureaucracy works very well in this kind of a dynamic industry," he says. "I don't know that it ever did, and I think that's another reason it's never really gotten any better."

According to NATCA, 41% of controllers work 10 hours a day, six days a week. A June report from the National Academies of Sciences, Engineering and Medicine, "The Air Traffic Controller Workforce Imperative," expressed concern that these staffing levels could cause fatigue and affect safety, either because controllers are working too many hours or because having fewer controllers results in a single controller working a combined position, when having assistance would be safer.

One of the 2025 incidents in the NASA database features such a scenario, where a controller reported failing to catch that an aircraft was coming in too low. The controller had been on position for at least two hours and was handling training as well as directing traffic.

"I feel that in the future controllers should be on position less than 2 hours, especially when training is involved," the controller wrote in the report.

In addition to juggling these tasks, controllers face tough shift patterns, such as the 2-2-1 or "rattler" shift. This schedule involves starting at 1:30 p.m. for two days, moving to a 7 a.m. start for the next two days, and then returning at 11 p.m. on the fourth day, with only eight hours off between the day and night shifts. This means a shorter work week and more time off after, but it also disrupts sleep patterns and can result in controllers getting as little as three hours of sleep between shifts, according to multiple FAA surveys. NATCA told me it is conducting a national review of the schedule with FAA to evaluate fatigue impacts.

Although hiring more controllers is an obvious solution, FAA has long struggled with recruitment. It's a well-paid job — with a median salary of around $145,000 as of May 2024, according to the Bureau of Labor Statistics — but it also requires a very particular skill set. Perhaps most importantly, controllers must be able to stay calm and solve problems in a three-dimensional space. This is hard to screen for in aptitude tests, and the pressure means plenty who initially sign up later walk away.

"When I was training at my first facility, there were times that I didn't think I was going to make it, because it was really hard — and I'd done this before," says Mark, who was an air traffic controller in the U.S. Air Force before spending a decade working in the tower and as an FAA supervisor. "Life is a challenge, and some people cope with it better than others."

Hoping to provide additional incentives, Duffy in May announced a plan to implement a 30% salary increase for new controllers, as well as a $5,000 bonus for those who graduate from the academy. He also is allocating extra resources to boost exam pass rates. To retain existing staff, the agency struck a deal with NATCA for incentives to encourage senior controllers to stay on for longer, rather than take early retirement, and to transfer to short-staffed facilities.

The FAA spokesman said the agency hired 2,026 new controllers as of September, meeting its 2025 hiring goal. The agency has also attempted to streamline the hiring process in various ways, he said, including working with

qualified institutes to get recruits on the job faster and enhancing training through the use of simulators.

Updating training and towers

Not only is it hard to find the right people, it's also becoming more difficult to train them. FAA has long been challenged to attract enough former controllers to serve as trainers — a job that's sometimes part time and usually requires spending part of the year in Oklahoma City, the main facility where instruction takes place.

FAA took steps to address this in late 2024 by allowing recruits to complete the first stage of training at eight other centers around the country, including Embry-Riddle Aeronautical University's Daytona Beach campus in Florida.

Once training is complete, new controllers are often sent off to aging towers, many of which are equipped with outdated technology and faulty wiring. FAA said in May the risk posed by these old buildings is greater than ever, highlighting failing infrastructure like HVAC systems, pest issues, leaking roofs and asbestos hazards. On a June visit to the San Diego tower, Duffy described how controllers had to jerry-rig the blinds to shade themselves from the hot California sun.

Part of the renovation challenge, notes Arel, is the vastness of the system — 406 towers across the country. That means upgrades often happen in small chunks, rather than in large swoops like what Duffy has proposed.

The system "has been modernized in increments when it can be afforded," says Arel, who spoke to me in October amid the government shutdown. That 43-day closure created an additional challenge, he says, because while controllers had to keep reporting to work, maintenance and renovation projects were halted.

"Things like shutdowns that are happening right now have stopped us incrementally as you start working on something."

As for the technology inside the towers, many of the 2025 reports referenced the continued reliance on paper, floppy disks and Windows 95. That matches up with the experience of Elaine Chao, who served as deputy transportation secretary for two years under former President George H.W. Bush and then in the department's top job during the first Trump administration. Little changed in the intervening two and a half decades, she says, recalling young recruits accustomed to iPhones having to use paper strips to track flights for landing and takeoff.

"We cannot continue to operate with a system that does not upgrade and modernize itself on a timely basis," she says. "Right now, it's still safe due to the tremendous skills of the men and women who run the air traffic control, but what happens when more and more of them begin to retire?"

The union Professional Aviation Safety Specialists, or PASS, which represents the technicians who maintain air traffic control equipment, says the problem is not just the aging equipment, but the challenges associated with acquiring replacement parts. Technicians are left trying to track down obsolete equipment, or even spare parts from a contractor that has gone out of business.

PASS President Dave Spero likened the strategy behind ongoing upgrades to "spreading the peanut butter a little thinner." Funding shortfalls have meant that rather than implementing a coherent system across the country at every facility, upgrades have been made in a patchwork fashion. This means there are multiple versions of various technologies, from voice switches to radars to automation and instrument landing systems. The impacts of this echo throughout the wider system, requiring extra training for technicians and controllers, extra classrooms and extra parts for maintenance.

"It's a bit like a car, if you keep running it," says Mark, the former controller. "At some point, if you're not really getting into the guts, it finally says 'I'm dead,' and it just won't work anymore. The stuff is just so old, and the process we have over here to bring in new equipment is so antiquated that it's kind of a perfect storm."

▲ Among the steps FAA has taken to expedite air traffic controller training is authorizing additional schools where trainees can complete their FAA Academy instruction. SUNY Schenectady in May became the sixth school to qualify for this program.

SUNY Schenectady County Community College

The way forward

Duffy's plan calls for building six new air traffic control centers and 15 towers with TRACONS (Terminal Radar Approach Control Facilities), as well as replacing aging infrastructure with new fiber, wireless and satellite technologies. Runway safety is also to be improved by bringing surface technology to more aircraft to enable real-time tracking of aircraft and ground vehicles.

The agency has set a 2028 target to achieve all this, and Duffy has vowed to move "at the speed of Trump." But that might be easier said than done. The famously bureaucratic agency has previously taken up to seven years to get new equipment, Chao recalls.

Spero of PASS shared similar experiences, adding: "If you're planning on doing it the way we've always done it, then that timeline is not realistic at all in any way, shape or form."

The government shutdown was the latest speed bump. Many federal workers did not receive paychecks between mid-October and early November. Media reports described air traffic controllers turning to second jobs or calling out sick, increasing the risk of delays and safety issues due to shortstaffing.

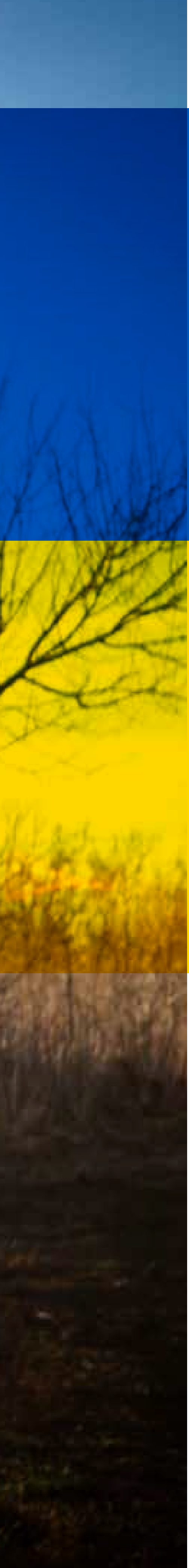
"The weight of being distracted, whether they're working another job or they're only working their FAA job, but not receiving enough income to cover their normal operating cost, that's something that we know weighs on individuals," says Arel. "Distractions aren't good in any safety-related profession."

Since 2005, lapses and reductions in funding associated with repeated shutdowns have had a negative impact on the air traffic control system, says Paul Rinaldi, head of operations and safety for the trade association Airlines for America. It's too soon to quantify the specific impacts of the 2025 shutdown, he says, but "the realistic view is it will interrupt all of the progress we're trying to make to make the system safer and more efficient."

So, where does the U.S. go from here? In Chao's view, it might be time to revisit the idea of privatizing the system, though she is loath to use that word. She tried to get a plan through Congress in 2017 that would have spun air traffic control out of the federal government and into a not-for-profit partly funded by the Aviation Trust Fund. The bill passed the House Transportation Committee but was never put up for a floor vote, and no similar proposals have been introduced in the years since.

"We've worked in this field for decades, and we've tried putting Band-Aids on it," she says. "We've tried to improve the procurement process. None of that seems to have worked." ★

A Ukrainian soldier releases a drone in 2022 in the Donetsk region in eastern Ukraine. AP/Roman Chop



BIG IMPACT ON SMALL DRONES

The ongoing Russia-Ukraine war has had an outsized influence on the development and use of small drones in the U.S. Keith Button spoke to manufacturers and researchers about the evolving landscape.

BY KEITH BUTTON | buttonkeith@gmail.com

On a recent visit to Ukraine, Brian Streem watched Ukrainian soldiers swapping out components of off-the-shelf consumer drones to modify them for battle.

"I'm sitting here watching frontline military guys de-soldering this commercially available device, removing a chip, and I'm like: 'How the [expletive] did anyone figure this out?'" says Streem, chief executive of New York-based Vermeer, which manufactures a visual navigation substitute for GPS. "There are certain things that we have absolutely learned about — like how these systems need to be integrated into other subsystems of the drone — that you just don't know without doing it and without seeing it."

Historically, experience gained from the battlefield has been applied to future doctrine and technology planning, due to the bureaucratic nature of weapon development and acquisition. But the Russia-Ukraine war has been different. Both countries are rapidly adopting and evolving their technologies, often updating them in a matter of days.

In the U.S., lessons learned since the start of Russia's invasion in early 2022 have already prompted academia, industry and military customers for the technology to shift their research priorities to reduce development timelines to months or even weeks.

Taking another lesson from the war, advocates for building up U.S. drone production are focusing on developing supply chains to easily source cheap components not made in China.

One means of achieving that objective could also have the side effect of reshaping U.S. airspace. Proponents argue that loosening FAA restrictions on small drones would expand U.S. commercial and consumer use, and thereby boost domestic drone manufacturing capacity.

The war has "changed our whole doctrine about how we're going to wage drone warfare in the future," says Jamey Jacob, an Oklahoma State University aerospace

engineering professor and small drone and counter-drone researcher. That change, he says, has been driven by "what they're doing there and how quickly they are doing it, adapting frontline modifications and manufacturing, rethinking everything."

Learning on the fly

U.S. researchers and entrepreneurs in the past were accustomed to developing and fielding new drone technologies on two- to five-year timelines, but Ukrainian and Russian soldiers have been adopting modifications and countermeasures within weeks. That's been the case particularly with small drones, Jacob says.

"We can no longer fight frontline battles like we had in the past," Jacob says. "We're seeing what that looks like now and how different that is from what we have prepared for."

The question now, he says, is how the U.S. can make a similar pivot, which includes how to manufacture the millions of small drones and their components that might be required for a future war. The U.S. Army plans to buy 1 million drones within three years, Reuters reported late last year, and then potentially ramp up to purchasing at least a half million drones per year, compared to its current outlay for 50,000 drones per year.

The Ukraine war has been "an accelerant" for small drone development in the U.S., especially by the Army and Marine Corps, says Andrew Hunter, a former Air Force acquisition chief who now consults for the defense industry and investors. His clients see a huge opportunity for drone manufacturers, he says.

"They see the effectiveness of what they do as being dramatically demonstrated" by the war, he says.

For Streem, who has five employees in Ukraine and an apartment in Kyiv, the war has also provided real-world development experience and data-gathering opportunities that would have been tough to replicate otherwise. For instance, suppose Vermeer wants to schedule a flight test in the U.S., he says. The company might get some time on "some California missile base next June."

"Great, that's nine months away from now," Streem says. "What else am I supposed to do until then?"

Vermeer is developing software that matches images from visual and infrared cameras, lidar, inertial measurement units and other inputs to digital maps to provide a radio-silent GPS substitute for drones carrying 40-60 kilograms of payload on 1,000-kilometer flights. Perfecting that software requires repetition.

"Getting stuff like this to work requires firing it on

▲ Ukraine's Ministry of Defense shared this photo in early 2024 of soldiers piloting a small drone.

108th Ukraine Territorial Defense Forces Brigade

"We can no longer fight frontline battles like we had in the past. We're seeing what that looks like now and how different that is from what we have prepared for."

— Jamey Jacob, Oklahoma State University

drones and missiles a lot, and taking a look at the data, figuring out what worked and what didn't work, and then why it didn't work, and then doing it again," Streem says.

The speed of need

In adopting lessons from Ukraine, the Defense Department and its contractors have placed a premium on quick turnarounds and lower costs per unit.

Some of the funding requirements for small drone research and development for the Air Force, Army and other defense programs have shifted since 2022 to prioritize low-cost options and need-it-yesterday results, says Moble Benedict, a Texas A&M University aerospace engineering professor and owner of Harmony Aeronautics, a drone development company.

"They want very, very rapid turnaround times now. It's not like a typical DOD kind of program where things happen in years," Benedict says. "They want these products in months — two months, three months. They're feeling the urgency to get into this drone space."

And many small companies are willing to oblige. "They are willing to do anything for success, so they will spend 18-hour days" to meet the stepped-up timelines, he says.

In addition to speedy development, the Pentagon is looking for relatively low-cost tech. Companies pitching counter-drone concepts are asked to present their "cost per kill," Benedict says. "If you're trying to take out a large UAS [unoccupied aerial system], a large asset costing many millions of dollars, you can send a very sophisticated UAS. But do you really want to send a sophisticated UAS to kill a $200 toy drone with a bomb strapped to it?"

Building a small drone from off-the-shelf parts is not complicated, he notes: You need an electric motor for the rotors, a battery, an electronic speed controller to convert the battery voltage for the motor, a power distribution board, a receiver for incoming radio signals, a flight controller to convert those signals to control the aircraft, a GPS receiver, a camera, a thermal camera, lidar, a 3D-printed frame, screws and wires.

But for that approach to really be cost-effective, the U.S. needs to start domestically mass-producing small drone components, Benedict says. Under Pentagon requirements, defense drones can't use parts or equipment from China, Iran, North Korea or Russia. But relying soley on approved U.S. suppliers can be expensive. The same kind of motor that sells for $20 from a Chinese vendor will cost $100 from a U.S. manufacturer, he says. U.S.-made electronics for drones are particularly expensive — driving the overall cost of a small drone to upward of $1,000.

"If you're free to use the cheapest available motor or the cheapest available battery you can buy online, you can build really cheap drones," he says. "But then the problem is all these supplies are coming from China."

One way to incentivize this domestic supply chain could be for FAA to loosen flight restrictions for commercial and recreational small drones, says Clinton Purtel, a business professor and aerospace supply chain expert at Oklahoma State University. This in turn could boost customer demand.

"Industry follows where you can use and scale the thing," Purtel says, noting that to date, U.S. manufacturers haven't made large-scale investments in producing small drone components because there's been no need.

"How do we get the pivot now so the production and specification is there and we don't have the critical path moment of: 'Oh crap, now we need it, now we're in combat?'" Purtel says. "How do we get on a level playing field for these things that are attritable, just no different than firing a round through a gun?"

Part of the reason for the urgency in the U.S. is the surprising lethality and precision that small drones have proven in Ukraine, Benedict says.

"One thing the world realizes right now is the kind of damage these drones can do and the kind of targeted attack that these guys can unleash," he says. "It's all because the Ukraine war has shown the world what you can do with drones." ★

Keith Button has written for C4ISR Journal and Hedge Fund Alert, where he broke news of the 2007 Bear Stearns hedge fund blowup that kicked off the global credit crisis. He is based in New York.

Lessons from Challenger

The space shuttle Challenger lifts off on Jan. 28, 1986, for flight STS-51L.

NASA

The Challenger and Columbia disasters reshaped NASA's processes and attitudes toward risk. Forty years after Challenger, David Ariosto examined its impact on regulations and the regulatory path forward for today's commercial operators.

BY DAVID ARIOSTO | dariosto@gmail.com

Forty years ago in January, the space shuttle Challenger broke apart 73 seconds after launch, shattering a growing impression that NASA's shuttle program had made human spaceflight relatively routine.

The technical cause of the death of the seven astronauts aboard was sobering — ignition of the main fuel tank traced back to faulty O-rings that allowed a leak in one of the solid rocket boosters — but perhaps even more so were the details unearthed by the Rogers Commission appointed by President Ronald Reagan. Over the course of a nearly three-year investigation, the commission found systemic flaws in NASA's management and organizational structure, as well as pressure to meet an "over-ambitious" target of 24 annual flights by the end of the decade.

In the disaster's aftermath came sweeping reforms: NASA created the Office of Safety, Reliability, and Quality Assurance; overhauled contractor oversight; and redesigned the boosters. What emerged was not just a reengineered space shuttle, but also a new model for governing U.S. spaceflight, born in part from shifting perspectives toward risk tolerance at NASA and beyond.

"As the findings of the Rogers Commission became apparent, and the investigation unfolded in public on television and in the newspapers, people began to see NASA in a very different way," says Adam Higginbotham, author of the 2024 book "Challenger: A True Story of Heroism and Disaster on the Edge of Space."

That reckoning would also reshape how the nation weighed risk, responsibility and the very cost of spaceflight. In the years since shuttle's retirement in 2011, a fundamentally different kind of era has taken shape, with private companies taking on a central role within a more limited regulatory regime intended to foster growth and innovation.

To date, Scaled Composites test pilot Michael Alsbury is the only person to die aboard a commercial space vehicle, during a 2014 flight test over the Mojave Desert. The National Transportation Safety Board (NTSB) concluded that Alsbury, who was co-piloting the SpaceShipTwo rocket-powered plane that Scaled was developing for Virgin Galactic, unlocked the vehicle's reentry "feathering" system too early, which caused the plane to break up. Pilot Peter Siebold parachuted to the ground with serious injuries, but survived.

David Ariosto
is co-host of the "Space Minds" podcast on Space News and author of the upcoming Knopf book, "Open Space: From Earth to Eternity–the Global Race to Explore and Conquer the Cosmos."

▲ Future investigations of commercial spacecraft might unfold differently than the Challenger investigation, conducted by a presidentially appointed commission. Here, commission chairman William Rogers (center) arrives at NASA's Kennedy Space Center for a briefing.

NASA

In the following years, passenger flights aboard privately owned and operated craft have begun in earnest. Since 2020, SpaceX has ferried 12 crews of professional astronauts to and from the International Space Station aboard its Crew Dragon capsules, in addition to four private flights to ISS and two free-flying flights to low-Earth orbit. As of Dec. 12, Blue Origin's New Shepard rockets and capsules and Virgin Galactic's VSS Unity spaceplane had conducted a combined 24 suborbital research and "tourist" jaunts. The majority of these passengers were private individuals who reportedly paid hundreds of thousands of dollars for a brief journey to the edge of space.

"People accept there's risks in just the basic physics of what we're doing," notes Terry Hart, a former NASA astronaut and mission specialist who flew on Challenger for the STS-41C mission two years before the STS-51L tragedy that took the lives of his colleagues.

In terms of oversight, FAA licenses the launch and reentry of these commercial craft, but is constrained from crafting regulations related to passenger safety because of a moratorium Congress approved in 2004 and has extended several times. Lawmakers established this "learning period," now set to expire in 2028, to allow the emerging commercial space industry to mature and evolve without the burden of full regulatory frameworks.

A disaster could change that.

There's precedent, notes Scott Hubbard, a former center director of NASA's Ames Research Center who participated in the investigation of the second shuttle disaster, the Columbia orbiter that broke apart during reentry in 2003. He pointed to railroads and early commercial aviation as examples of growing industries in which fatalities sparked increased regulations.

"These types of endeavors, once they have involved

massive tragedies, then people come in and say, 'You know, we probably ought to have better code,'" he says.

Differing approaches

Debates about risk assessment echo an older story — one that NASA confronted decades earlier. In the weeks and months preceding that cold day in January 1986, engineers worried about the O-rings in the solid rocket boosters positioned on both sides of shuttle's external tank. These seals, meant to prevent hot gases from seeping through the joints of the boosters during combustion, were known to behave poorly in low temperatures.

Engineers at Morton Thiokol, which manufactured the boosters, had initially recommended standing down from the launch. Management reversed that the day before, the Rogers Commission concluded, "to accommodate a major customer."

In the disaster's aftermath, the agency's old "failure is not an option" mantra — a phrase often associated with flight director Gene Kranz and the troubled Apollo 13 mission — seemed to take on new resonance. But in today's commercial age, NASA is increasingly a customer purchasing services, rather than an owner and operator of hardware. Private companies now shoulder more of the risk, and speed, cost and market pressures have become part of the calculus in ways that NASA has never experienced.

With founders like Elon Musk and Jeff Bezos having earned their chops in software, rapid iteration is a hallmark of many modern space companies — particularly SpaceX, the world's leading provider of satellites, cargo and crewed launches.

For Brewster Shaw, a retired NASA astronaut who flew on three shuttle missions, the differing attitudes toward

▲ Since 2022, Axiom Space of Texas has conducted four private missions to the International Space Station, all aboard SpaceX Dragon capsules. In this photo from June, Axiom-4 commander Peggy Wilson (in blue) and mission specialist Shubhanshu Shukla of the Indian Space Research Organisation work in the station's Kibo laboratory.

NASA

risk amount to distinct cultures.

"I look back at when I was working for Uncle Sam, and then I look back when I was working for Boeing, and I was doing the same thing in both of the jobs," says Shaw, who spent seven years at Rockwell and then Boeing overseeing development of components for ISS. "But I had cut my teeth working for NASA. And so I think that [sense of risk] gets ingrained."

SpaceX leadership advocates for real-world stress testing and the iterative improvements gained from successive launches as the best way to enhance the safety and reliability of their vehicles.

"It's called exploring the corners of the box," Musk told podcaster Joe Rogan in late October of his company's approach. "We intentionally subject [the vehicle] to a flight regime that is much worse than what we expect in normal flight, so that when we put people onboard, or valuable cargo, it doesn't blow up."

That approach has made for an "incredibly robust system design," Gwynne Shotwell, SpaceX's president and chief operating officer, said during a late 2024 event at the Center for Strategic and International Studies in Washington, D.C.

Indeed, over its roughly 500 launches since 2010, the Falcon 9 rockets have had a less than 1% failure rate. Today, SpaceX is responsible for more than 90% of the payloads launched into space.

And the company has even bigger hopes for the behemoth Starship-Super Heavy rockets that are central to Musk's ambition of establishing a self-sufficient Mars city. Aspirations include launching up to 500 Starships during the 2033 transfer window to Mars, Musk said during a May presentation. Long term, each Starship could carry up to 200 passengers.

Given these ambitions and those of other companies, some experts say it could be time to revisit the learning

▲ The 2014 crash of Virgin Galactic's SpaceShipTwo was the first and only time the National Transportation Safety Board investigated an incident involving a commercial space vehicle.

National Transportation Safety Board

period and update regulations.

"Things have been going well for a while, but we have a long way to go in terms of how we want to move forward," says George Nield, a former head of FAA's Office of Commercial Space Transportation that licenses launches. "That means at some point we're going to want to transition away from continuing to extend the moratorium, which some people call the learning period, and adopt a new framework."

Mary Guenther, head of space policy at the Progressive Policy Institute, formerly of the Commercial Space Federation, is among those advocating for a slower approach: "a glide path" that allows for a broader regulatory framework to be adopted over time.

"I don't think the industry is ready to go from zero to 60 — limited regulation to full regulation," she says. "There are still vehicles coming online. Your Dream Chaser looks a lot different from your New Glenn, and much different from your Starship. A full-scale certification regime may not be appropriate in the short term. But over time, we better understand the risk profile of these vehicles."

A bill introduced in 2024 would have pushed the learning period out to October 2031, but it failed to pass both chambers of Congress.

Investigating future crashes

In terms of logistics, the U.S. government has established the broad brushstrokes of how to investigate commercial space mishaps and fatal accidents. NTSB would lead any investigation in which there is a "fatality or serious injury to any person, regardless of whether the person was on board the commercial space launch or reentry vehicle," according to a 2022 agreement with FAA. That agency would oversee investigations of any other mishaps.

NTSB also led the investigation into the 2014 crash of SpaceShipTwo, the first time the agency conducted a full investigation of a crewed commercial spacecraft.

"This has many similarities and some differences" to past investigations, acting NTSB chairman Christopher Hart told reporters shortly after the crash.

Like for its other investigations, NTSB issued a final report that determined the crash's probable cause and detailed recommendations. Among them was for FAA to work with the Commercial Space Federation to "develop and issue human factors guidance for operators."

Guenther expects regulation to increase as the industry matures and its workforce grows.

"As [spaceflight] becomes less of an active choice," she says, referring to plans that would require people to regularly work and travel beyond Earth's atmosphere, "and as we move along that continuum, that is when regulation will grow."

"But it's challenging to know how the Congress or the public will respond," she adds.

History suggests that any passenger deaths could quickly prompt increased regulation. In 1931, for instance, Notre Dame head football coach Knute Rockne and seven others were killed when their Fokker F-10 crashed a few miles west of Bazaar, Kansas. President Herbert Hoover declared it "a national loss," and all Fokker F-10s in the U.S. were temporarily grounded, pending inspections. Thereafter, the Aeronautics Branch, FAA's precursor, took on a larger role in aircraft certification and began publishing the results of accident investigations.

Beyond the regulatory response, a tragedy could also prompt the involved company to take action. Consider, for example, the two fatal crashes in 2018 and 2019 involving Boeing's 737 MAX, which led to a nearly two-year grounding and some $20 billion in financial losses. In response to the crash investigations, Boeing developed a software update to the implicated flight control system and overhauled pilot training protocols.

Still, Nield stressed the need for an overarching structure and framework, one that "would allow industry to take advantage of the advanced technologies and the new ways of doing business, while still benefiting from all of the lessons that we've learned over the past 60-plus years of human spaceflight, including what we've learned from Challenger."

Revising the regulations

In the absence of congressional action, the industry could still begin creating such a framework today, Nield says. He suggested greater reliance on independent safety institutes to foster increased collaboration, transparency and data sharing, "especially when we're talking about safety-related accidents, incidents and close calls."

"It doesn't have to be a one size fits all," he adds. "We can have lots of options for approving these operations."

The idea would be to clarify lines of responsibility. With NASA operating Challenger and Columbia, the agency held both decision-making authority and ultimate accountability. By contrast, commercial spaceflight involves multiple stakeholders, including the operating company, regulators and potentially passengers who assume certain risks.

That muddled picture, Hubbard says, is precisely what a more defined framework could address.

"It doesn't mean we necessarily have to have a lot of detailed regulations," he notes. "It could involve using industry and consensus standards," private oversight or an institute that reviews and certifies operations.

Agility is top of mind for Guenther, given what she described as "the growing competition" between the U.S. and China to land astronauts on the moon this decade.

Acting NASA Administrator Sean Duffy echoed those sentiments during a September town hall.

"We are safety-driven, and we should be safety-driven," Duffy said, according to a recording of the event posted by NASA Watch. "Sometimes we can let safety be the enemy of making progress."

"We have to be able to take some leaps," he added. "We can't side on the side of doing nothing because we're afraid of any risk." ★

GODDARD CENTENNIAL SERIES

This is the third in a three-part series commemorating the 100th anniversary of the launch of the first liquid-propellant rocket on March 16, 1926.

Esther Goddard: keeper of her husband's legacy

Uneasy as Robert H. Goddard was with public attention, much of his research could have been lost after his death in 1945 from throat cancer — if not for his wife, Esther. She collected his papers, secured patents and worked with various institutions to establish exhibits and awards. Roger Launius and Jonathan Coopersmith explore Esther's role as Goddard's constant collaborator and champion.

BY ROGER D. LAUNIUS AND JONATHAN C. COOPERSMITH

Esther Goddard in 1937 in New Mexico. The portrait appears in the final section of the annotated photo album, "The Goddard Rocket Researches: A Photographic Record," that Esther compiled and published after her husband's death in 1945.

Clark University

Worcester, Massachusetts, was the center of Esther Christine Kisk Goddard's life. She spent the majority of her life there, only journeying elsewhere between 1930 and 1945 when her husband, rocket pioneer Robert H. Goddard, relocated near Roswell, New Mexico, to pursue his experiments in the desert.

They met in 1919, while Esther was employed as a secretary at Clark University and attending Bates College. Although separated by a 20-year age gap, their shared intellectual curiosity and mutual respect laid the foundation for their marriage — a union that evolved into a lifelong collaboration that significantly shaped both their personal lives and Goddard's path-breaking work in rocketry. After marrying in 1924, Esther and Robert Goddard moved to Maple Hill Farm near Worcester, their home until they left for Roswell in 1929. She worked tirelessly to refurbish the house and make it comfortable. Naturally more outgoing than her husband, Esther also helped Robert become more socially engaged, remembering in her edited collection of Goddard's papers: "The younger faculty people were casual and Bob liked them. He began to mix more easily."

Esther became a dedicated assistant to her husband, photographing his launches; deciphering his notes — which only she could read — into easily digestible information; keeping his account books; sewing his payload parachutes for rocket launches; even putting out brush fires caused by rocket tests; and doing whatever else needed to be done. She described their life as "poised at the edge of achievement," a phrase that seemed to capture both the excitement and delicateness of their efforts together.

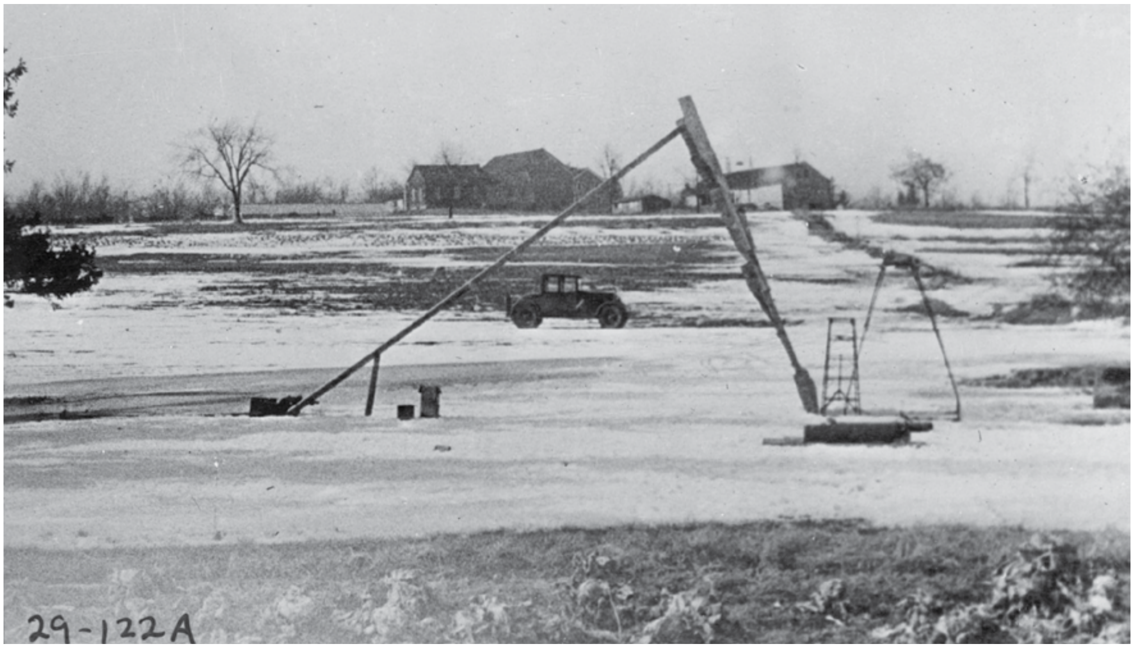
When they moved to the Mescalero Ranch near Roswell, which she considered "High Lonesome," Esther not only continued her dedication to her husband's research, but also served as his interface with the town. She founded a women's club in Roswell as well as a book club that still exists. She expressed that this move provided "optimum surroundings" for her husband's work away from the East Coast and offered relief from his nagging respiratory issues.

"During the fruitful years of full-time experimentation, financed by the Guggenheim family, he was an extremely happy man, doing what he most wanted to do, with adequate funds in optimum surroundings," Esther recalled in her edited collection of Goddard's papers.

At the same time, their New Mexico home was spartan; when Charles and Anne Morrow Lindbergh visited them in the latter 1930s, Esther remembered: "We had no beds and scarcely chairs to offer them … but we were not permitted to feel embarrassed."

Soon after the start of World War II, the Goddards moved again, this time to Annapolis, Maryland, where Robert worked for the U.S. Navy on military rocketry until his death in 1945 from throat cancer. He was 62.

Thereafter, Esther earned a master's degree from Clark



This photo is believed to show the testing apparatus for Robert Goddard's historic March 1926 launch of the first liquid-fueled rocket. Esther Goddard recorded the test on her 16 mm film camera and extracted this still, captioning it "testing frame and wind break" in the album "The Goddard Rocket Researches: A Photographic Record."

Esther Goddard via Clark University

Roger Launius is a former chief historian of NASA and associate director for collections and curatorial affairs at the Smithsonian National Air and Space Museum in Washington, D.C.

Jonathan Coopersmith is a historian of technology and former professor at Texas A&M University in College Station who has written about 20th century space commercialization.

University in 1951, served as a university trustee from 1964 to 1970 and received an honorary degree from the university in 1972. Like many widows — think Jessie Benton Frémont, who kept alive the legacy of her husband, John Charles Frémont — Esther devoted much of her final 20 years to promoting her husband's work and ensuring he received credit for his rocketry innovations.

His patents became a major focus. Working with attorney Charles Hawley, she secured 131 of her husband's 214 patents. She also immediately undertook efforts to secure payment for any damages due from patent infringement, submitting a complaint to the U.S. Army in 1957.

Konrad K. Dannenberg, who had accompanied the rocket team of Wernher von Braun from Germany to the United States in 1945, received the complaint. Director of the Technical Liaison Group for the Army Ballistic Missile Agency (ABMA), in Huntsville, Alabama, Dannenberg passed the correspondence on with a DD95 routing memorandum containing a handwritten note: "Forwarded to you as a matter pertaining principally to your Section. Sympathetically!"

"Sympathetically" was underlined five times. Dannenberg, or some other ABMA official, certainly appeared understanding of Esther's position on the matter.

Responsibility for the investigation landed on the desk of Dave Christensen, a young engineer involved in the Redstone and Jupiter missile development programs who would later go on to work on the Saturn I H-1 engine. He found that infringement of Goddard's patents had indeed taken place and recommended paying Esther a settlement. By the time this happened, the rocket program at ABMA had moved from the Army to NASA, and in 1960 the space agency settled the case with a $1 million payout to Esther.

The case was a landmark in intellectual property; it allowed Esther to secure not only resources for the future but also official recognition that her husband's innovations had made America's spaceflight achievements possible. While the case was being settled, NASA named its new space laboratory outside of Washington, D.C., the Goddard Space Flight Center, to honor Goddard's legacy.

Perhaps even more significantly, Esther meticulously sorted and organized her husband's papers, donating them to Clark University, where they found an honored place in the Goddard Library after its opening in 1969. Focused on ensuring her husband's recognition, she used the funds from the patent infringement settlement for publications, museum donations and educational outreach.

She edited and published her husband's book, "Rocket Development: Liquid Fuel Rocket Research, 1929-1941" in 1961. She also collaborated with G. Edward Pendray, a founder of the American Interplanetary Society and a passionate space exploration advocate, to produce the three-volume set "The Papers of Robert H. Goddard," published in 1970. A comprehensive account of his life and work, this 1,700-page set remains an indispensable source on Goddard's career as America's foremost early rocket developer.

Esther wrote in her introduction to the book, "This work is the result of many years of effort to preserve and present the record of a man whose vision and persistence opened the way to space flight."

In undertaking this project, which spanned more than a decade, Esther commented: "It has been a labor of love, and at times a lonely one. But I felt it was my duty to make sure that his voice would not be lost."

Esther tirelessly labored to ensure that museums around the country celebrated Robert's legacy. In 1965, she donated his 1916 Magnesium Powder Experiment Box to the Smithsonian. It remains the oldest space-oriented artifact in the national collection. She also contributed materials to the Roswell Museum, helping establish the Robert H. Goddard wing in 1969. In every instance, Esther

◀ Among the facilities dedicated to her husband that Esther Goddard (far right) helped establish is the Goddard Library at Clark University, which opened in 1959.

Clark University

ensured that her husband received his due as a foundational figure in space engineering.

Without question, Esther Christine Kisk Goddard was not merely Robert Goddard's wife — she was also his indispensable partner, collaborator and steward of his legacy. Esther passed away in 1982, but her impact endures through her efforts to document and publicize her husband's legacy. ★

ABOVE + BEYOND

AIAA'S PHOTO SECTION HIGHLIGHTING THE BEST IMAGES OF THE QUARTER

On 13 November, the New Glenn orbital launch vehicle successfully completed its second mission, deploying NASA's Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE) twin-spacecraft into the designated loiter orbit, and landing the fully reusable first stage on Jacklyn in the Atlantic Ocean. Blue Origin


JACKLYN
BLUE ORIGIN
LANDING PLATFORM VESSEL 1


NASA
X-59

NASA's X-59 quiet supersonic research aircraft lifted off for its first flight 28 October 2025, from the Lockheed Martin Skunk Works' facility at U.S. Air Force Plant 42 in Palmdale, California. The one-of-a-kind aircraft flew for 67 minutes before landing and taxiing to NASA's Armstrong Flight Research Center. The aircraft's first flight marked the start of flight testing for NASA's QueSST mission, the result of years of design, integration, and ground testing.

Main Image: NASA/Carla Thomas Inset photo: NASA/Lori Losey

From the Institute

JANUARY-MARCH | AIAA NEWS AND EVENTS

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2026			
11 Jan	7th AIAA Propulsion Aerodynamics Workshop	Orlando, FL (aiaa.org/courses/aiaa-propulsion-aerodynamics-workshop-paw)	
12–16 Jan	AIAA SciTech Forum	Orlando, FL	22 May 25
26 Jan–20 Feb	AIAA Election		
31 Jan	Carolina Aerospace Symposium	Charlotte, NC	
9 Feb–25 Mar	Design of Space Launch Vehicles Course	ONLINE (learning.aiaa.org)	
17 Feb–12 Mar	Verification & Validation for High Temperature Material Modeling & Applications Course	ONLINE (learning.aiaa.org)	
18–19 Feb*	CFD Validation Challenges: Perspectives from Modelers and Measurers	London, UK (www.aeroconf.org)	
24 Feb–2 Apr	Aircraft Performance for Advanced Air Mobility: A Path to Certification Course	ONLINE (learning.aiaa.org)	
25–26 Feb	ASCENDxTexas	Houston, TX	
2 Mar–1 Apr	Spacecraft Lithium-Ion Battery Power Systems Course	ONLINE (learning.aiaa.org)	
3–26 Mar	Vortex Flow Aerodynamics Course	ONLINE (learning.aiaa.org)	
7–14 Mar*	IEEE Aerospace Conference	Big Sky, MT (www.aerosociety.com)	
9 Mar–8 Apr	Engineering Design Optimization: Theory and Practice Course	ONLINE (learning.aiaa.org)	
10 Mar	Dayton-Cincinnati Aerospace Sciences Symposium	Dayton, OH	
17–20 Mar	AIAA DEFENSE Forum	Laurel, MD	14 Aug 25
17–19 Mar	Understanding Space: Intro to Astronautics and Space Systems Engineering Course	ONLINE (learning.aiaa.org)	
17 Mar–7 Apr	Fundamentals of Python for Engineering Programming and Machine Learning Course	ONLINE (learning.aiaa.org)	
21–22 Mar	AIAA Region VI Student Conference	San Luis Obispo, CA	23 Jan 26
23 Mar–1 Apr	Technical Writing Essentials for Engineers Course	ONLINE (learning.aiaa.org)	
24 Mar–16 Apr	Systems Engineering and Responsible AI for Aerospace Applications Course	ONLINE (learning.aiaa.org)	
26–27 Mar	AIAA Region II Student Conference	Columbia, SC	Jan 26
26–27 Mar	AIAA Region V Student Conference	Ames, IA	31 Jan 26
27–29 Mar	AIAA Region IV Student Conference	Houston, TX	30 Jan 26
30 Mar–2 Apr	Space Mission Operations Course	ONLINE (learning.aiaa.org)	

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2026			
6–13 Apr	Spacecraft Design, Development, and Operations Course	ONLINE (learning.aiaa.org)	
7–9 Apr*	5th IAA Conference on Space Situational Awareness	Madrid, Spain (https://iaaspace.org/event/)	15 Dec 25
10–11 Apr	AIAA Region III Student Conference	Ann Arbor, MI	6 Feb 26
12–13 Apr	AIAA Region I Student Conference	College Park, MD	2 Feb 26
13–15 May*	1th International Conference on Recent Advances in Air and Space Technologies (RAST2026)	Istanbul, Turkey (https://rast.org.tr/)	
16–19 Apr	30th Annual Design/Build/Fly Competition	Wichita, KS (USA)	
18 Apr	Pacific Northwest Technical Symposium	Seattle, WA	
25 Apr	Southern California Aerospace Systems and Technology Conference	Irvine, CA	
18 May	2026 AIAA Fellows Induction Ceremony and Dinner	Washington, DC	
19–21 May	ASCEND 2026 Powered by AIAA	Washington, DC	18 Sep 25
26–29 May*	32nd AIAA/CEAS Aeroacoustics Conference	Brussels, Belgium	19 Nov 25
26–29 May*	ICNPAA 2026: Mathematical Problems in Engineering, Aerospace and Sciences	Sanlirufa, Turkey (https://event.fourwaves.com/icnpaa2026/pages)	
1–5 Jun*	28th Aerodynamic Decelerator Systems Conference and Seminar	London, United Kingdom	18 Dec 25
8–12 Jun	AIAA AVIATION Forum	San Diego, CA	13 Nov 25
15–20 Jun*	2026 International Rocket Engineering Competition (IREC)	Midland, TX	
21–25 Jun*	US Congress on Theoretical and Applied Mechanics	Pasadena, CA (www.nationalacademies.org/our-work/us-national-committee-for-theoretical-and-applied-mechanics-usnc-tam)	
7–10 Jul*	27th AIAA International Space Planes and Hypersonic Systems and Technologies Conference	Naples, Italy	
26–30 Jul*	2026 AAS/AIAA Astrodynamics Specialist Conference	Whistler, British Columbia, Canada (space-flight.org/docs/2026_summer/2026_summer.html)	
1–9 Aug*	46th Scientific Assembly of the Committee on Space Research (COSPAR 2026) & Associated Events	Florence, Italy (cospar2026.org)	
5–9 Oct	76th International Astronautical Congress	Antalya, Turkey	

**Meetings cosponsored by AIAA. Cosponsorship forms can be found at aiaa.org/events-learning/exhibit-sponsorship/co-sponsorship-opportunities.*

AIAA Continuing Education offerings

FOR MORE INFORMATION on meetings listed below, visit our website at aiaa.org/events or call 800.639.AIAA or 703.264.7500 (outside U.S.).

AIAA Announces Its Class of 2026 Associate Fellows

AIAA is pleased to announce its newly elected Class of 2026 Associate Fellows. The grade of Associate Fellow recognizes individuals "who have accomplished or been in charge of important engineering or scientific work, or who have done original work of outstanding merit, or who have otherwise made outstanding contributions to the arts, sciences, or technology of aeronautics or astronautics." To be selected as an Associate Fellow an individual must be an AIAA Senior Member in good standing, with at least 12 years of professional experience, and be recommended by three AIAA members.

The Institute will honor the class at the AIAA Associate Fellows Induction Ceremony and Dinner, Wednesday, 14 January 2026, during AIAA SciTech Forum 2026, 12–16 January.

Class of 2026 AIAA Associate Fellows

Ajit Achuthan, Clarkson University

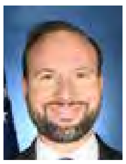
Kevin R. Anderson, California State Polytechnic University, Pomona

Dale C. Arney, NASA Langley Research Center

Dilmurat M. Azimov, University of Hawai'i at Mānoa

Damiano Baccarella, University of Tennessee

Sean Bailey, University of Kentucky



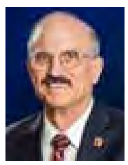
Brent W. Barbee, NASA Goddard Space Flight Center / University of Maryland, College Park

Tadas P. Bartkus, Ohio Aerospace Institute

Tahllee Baynard, Lockheed Martin Space

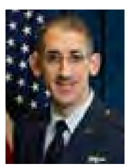
David R. Beering, Intelligent Designs LLC

Kevin D. Bell, The Aerospace Corporation



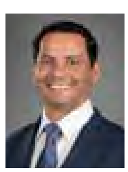
Mark G. Benton Sr., Embry-Riddle Aeronautical University, Prescott, Arizona

Reid A. Berdanier, Pennsylvania State University



Robert A. Bettinger, Air Force Institute of Technology

Natasha Bosanac, University of Colorado Boulder



Pablo C. Bueno, Southwest Research Institute

Goutam Chattopadhyay, NASA Jet Propulsion Laboratory

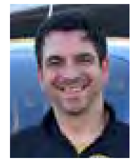
John G. Clark, SynthBee

Cameron W. Coates, Kennesaw State University

Richard K. Cohn, Ursa Major Technologies

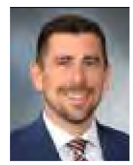
Lt. Col. Christopher Coley, United States Air Force

Velibor Ćormarković, NASA Jet Propulsion Laboratory



Christopher Courtin, Electra.aero

Beni Cukurel, Technion—Israel Institute of Technology



Daniel R. Cuppoletti, University of Cincinnati

Danielle S. Curcio, RTX

Andrea Da Ronch, University of Southampton

Scott T M Dawson, Illinois Institute of Technology


Jan W. Delfs, German Aerospace Center (DLR)


Edward P. DeMauro, Rutgers, The State University of New Jersey


Benjamin Dickinson, Air Force Research Laboratory


Con J. Doolan, University of New South Wales

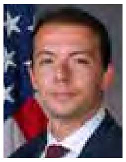

Christopher Brian Dreyer, Colorado School of Mines


Harold Ennulat, Software Engineering Institute


Alper Erturk, Georgia Institute of Technology


Antony D. Evans, Airbus


Nicolas Fezans, German Aerospace Center (DLR)


Matthew L. Fotia, Air Force Research Laboratory


Jacob George, Metrolaser Inc.


Leslie Gertsch, Missouri University of Science and Technology


Ritesh Ghimire, United States Federal Aviation Administration


Keith D. Goodfellow, Aerojet Rocketdyne / L3Harris


Amelia D. Greig, BAE Systems Inc.


Mark Robert Grindle, Systems Enginuity

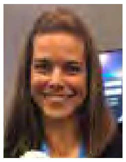

Peter Hancock, University of Central Florida


Darren John Hartl, Texas A&M University


Liam M. Healy, Naval Research Laboratory


Jesse B. Hoagg, University of Kentucky


Kristin Houston, L3Harris Technologies


Erin Hubbard, NASA Glenn Research Center


Lester A. Ingham, Honda Aircraft Company


Louise Jandura, NASA Jet Propulsion Laboratory


Elishka L. Jepson, RTX


Michael Jones, Systems Technology, Inc.


Daewon Kim, Embry-Riddle Aeronautical University


Hyun Jung Kim, KAIST


Michael P. Kinzel, Embry-Riddle Aeronautical University


Julie E. Kleinhenz, NASA Glenn Research Center


Ali R. Kolaini, NASA Jet Propulsion Laboratory

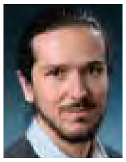

Ramesh Kolar, U.S. Army DEVCOM AvMC TDD-A DSE CD&A


Jarret M. Lafleur, Ursa Major Technologies


Rhea P. Liem, Imperial College London


Yu Cheng Liu, Tsinghua University


Yang Liu, City College of New York


Francisco Lopez Jimenez, University of Colorado Boulder


Alejandro Lopez Ortega, NASA Jet Propulsion Laboratory


Mark H. Lowenberg, University of Bristol


Christopher A. Lupp, Air Force Research Laboratory


Ou Ma, University of Cincinnati


Lori A. Magruder, University of Texas at Austin


Luca Massa, Virginia Polytechnic Institute and State University


Ellen Yi Chen Mazumdar, Georgia Institute of Technology


Matthew McCrink, Ohio State University

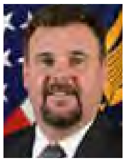

Matthew McGilvray, University of Oxford


Michael D. McPartland, MIT Lincoln Laboratory


Marcel Milanes, Lockheed Martin Aeronautics


Michael Z. Miller, Georgia Tech Research Institute

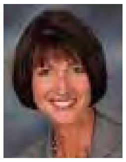

Guy Juan Montoro, Lockheed Martin Aeronautics


James D. Moreland, Jr., MEI Innovative Solutions Inc.


Catalin C. Nae, INCAS – National Institute for Aerospace Research "Elie Carafoli"


Björn Nagel, German Aerospace Center (DLR)


Douglas J. Neill, Computational Engineering Software, LLC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Mark Olmos, Northrop Grumman Space Systems


Michael Otte, University of Maryland, College Park


Ganesh J. Pai, KBR


Pinaki Pal, Argonne National Laboratory


Amit Pandey, Lockheed Martin Space Systems


Marco Pavone, Stanford University / NVIDIA

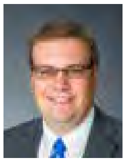

Tanya Pemberton, The Aerospace Corporation


Daniel Plakosh, Carnegie Mellon University / Software Engineering Institute


Brent Pomeroy, NASA Langley Research Center


Savio James Poovathingal, University of Kentucky


Russell W. Powers, Naval Air Warfare Center Aircraft Division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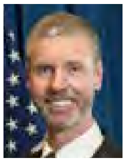
Nilton O. Renno, University of Michigan


Christopher L. Reynolds, Lockheed Martin Corporation


Daniel R. Richardson, Sandia National Laboratories


James L. Rutledge, Lockheed Martin Space


Umberto Saetti, University of Maryland, College Park

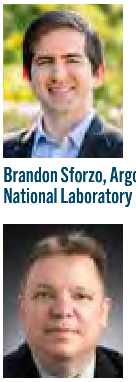

Marco Sagliano, University of Bologna


Abhishek Saha, University of California, San Diego

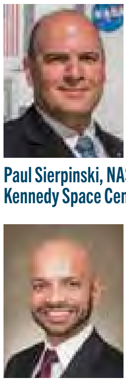

Gerald B. Sanders, NASA Johnson Space Center (retired)


Grady Pike Saunders, Amentum Technology, Inc.

Bryan E. Schmidt, Case Western Reserve University


Brandon Sforzo, Argonne National Laboratory

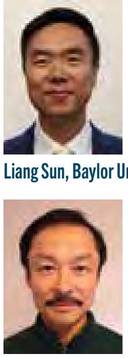
Peter J. Sharer, Johns Hopkins Applied Physics Laboratory


Paul Sierpinski, NASA Kennedy Space Center

Rohan Sood, University of Alabama, Tuscaloosa


Shawn S. Stephens, United States Air Force

James P. Stewart, Electra.aero


Liang Sun, Baylor University

Takao Suzuki, Boeing Commercial Airplanes


Hideyuki Taguchi, Japan Aerospace Exploration Agency


James Chris Thomas, Southwest Research Institute

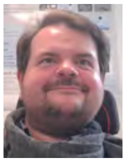

Diane C. Villanueva, The MITRE Corporation


Brian S. Woodard, University of Illinois Urbana-Champaign


Bo Zhang, Shanghai Jiao Tong University


Dianyun Zhang, Purdue University


Jimmy C. Tai, Georgia Institute of Technology


Christoph Torens, German Aerospace Center (DLR)


James M. Walton, Lockheed Martin Aeronautics


Kris Zacny, Honeybee Robotics, a Blue Origin Company


Yufei Zhang, Tsinghua University


Wenwen Zhao, Zhejiang University


Jekan Thangavelautham, University of Arizona


Paul J. van Susante, Michigan Technological University


Alan Weston, Astra


Hossein Zare-Behtash, Emirates Aviation University


Liwei Zhang, University of Texas at Arlington

MAKING AN IMPACT

Celebrating 30 Years:

AIAA Foundation Paving the Way for the Next Generation of Aerospace Educators, Engineering Leaders

By Anne Wainscott-Sargent

For three decades, the AIAA Foundation has promoted aerospace education, recognized excellence, and inspired future aerospace professionals. "The AIAA Foundation has been a powerful force in helping countless students and educators discover the wonder of aerospace," remarked AIAA President Dan Hastings.

As we celebrate the AIAA Foundation's 30th anniversary, we recognize that strong support by AIAA members has enabled the Foundation to achieve significant impact over the last three decades: more than 1,900 K–12 classroom grants delivered STEM opportunities to over 300,000 young learners; over 1,500 aerospace scholarships have unlocked academic doors; more than 500 student conferences have given aspiring engineers a stage; and upward of 34,000 university students have immersed themselves in hands-on technical design competitions.

According to Alexandra D'Imperio, the Foundation's director, the focus from the start has been on inspiring and supporting the next generation, noting that the support has ranged from endowing new programs to establishing classroom grants and supporting hands-on educational events. "The Foundation's reputation for giving back has especially resonated with AIAA's longstanding members, with many wanting to create a legacy through the Foundation," D'Imperio added.

Design/Build/Fly Competition

The organization's most well-known competition, Design/Build/Fly, allows university students to apply real-world aircraft design experience by creating a novel, remote-controlled aircraft manufactured for a specified mission. DBF allows students to build their skills in design as well as teaming and problem-solving needed in today's job market.

"What sets DBF apart is the hands-on challenge – students aren't just theorizing, they're building, breaking, fixing, and collaborating. They face real-world problems with real stakes," D'Imperio explained.

The competition's growth – from just 11 teams when it first began in 1996 to over 170 applicants annually – mirrors the field's expanding horizons. Employers, D'Imperio noted, "know these students have gotten their hands dirty. The ability to work in teams and solve tough problems gives them a tremendous head start in their careers."

"Design/Build/Fly has set me up well with many skills required in the industry – including technical writing and documentation, leading a team, maintaining regulatory compliance, and transferring knowledge to people coming after me. All that, combined with the quality advice I can obtain from AIAA mentors, will enable me to have a successful career in this industry," said Tushar Khosla, whose University of Illinois Urbana-Champaign's AeroE team finished 25th out of 107 teams in the 2024 competition when he was flight test lead. Khosla graduated in May with honors from the AeroE program and now works as a systems safety engineer at Collins Aerospace.

Beyond headline programs, the Foundation's classroom grants have enabled educators to create memorable, interactive STEM experiences, while student conferences provide safe spaces for hundreds of emerging scholars to develop their research presentation skills and professional confidence.

Broadening Focus to Include Technical Trades

Looking to the future, the Foundation must adapt its mission to reflect the workforce needs of a rapidly evolving industry, which faces widening skill gaps and an aging labor force. Laura McGill, chair of the AIAA Foundation and director of Sandia National Laboratories, emphasized, "As industry demand for engineers and scientists continues to outpace the available workforce, we know that investing in early education and student engagement is more critical than ever."

Recent OEM forecasts find that the U.S. aerospace sector will need an additional 123,000 technicians over the next 20 years, prompting the industry to step up efforts to recruit workers from technical colleges and two-year schools.

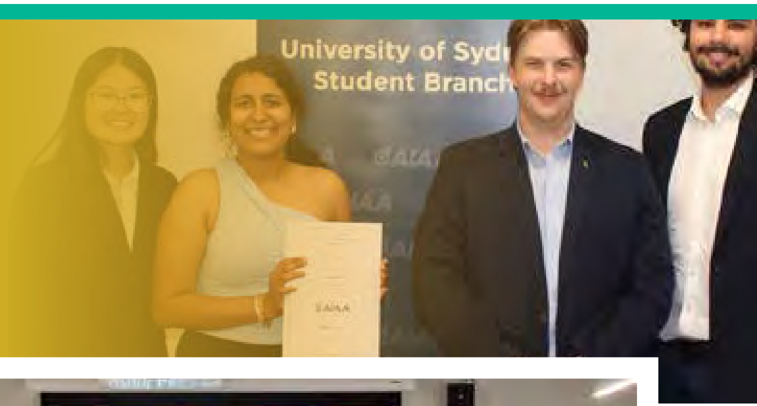
Similarly, the AIAA Foundation is expanding opportunities for high school and community college students, and introducing non-traditional career pathways to reach a broader, more diverse pool of future aerospace professionals. Now more than ever, the Foundation is dedicated to showing all students – not just future engineers, but also skilled technicians – the variety of roles available across aerospace.

AIAA Foundation Day of Giving Was a Success!

The AIAA Foundation celebrated its fourth annual Day of Giving on 2 December 2025, and with the support of 87 generous donors, we raised more than $61,000! These funds will help fuel the aspirations of the next generation of aerospace innovators and explorers.

Thanks to the continued generosity of the AIAA community, the Foundation will be able to provide over $160,000 annually in scholarships and graduate awards to high school seniors and university students. Additionally, we will distribute $77,000 each year in K-12 educator awards and grants, supporting hands-on programs like Design/Build/Fly, student conferences, and so much more.

There's still time to make a difference! To contribute to the AIAA Foundation and help shape the future of aerospace, visit **aiaa.org/foundation.**



AIAA Announces 2025 Region VII Student Conference Winners

AIAA is pleased to announce the winners from the 2025 Region VII Student Conference, hosted at the University of Sydney, 1–2 December, both in person and virtually. Additionally, the papers presented at the conference will be published by AIAA and available on Aerospace Research Center (ARC) at the beginning of 2026.

Attendees presented 54 papers and represented 23 schools. The conference had a strong international presence with students from 9 countries including Australia, Bangladesh, India, Netherlands, New Zealand, Norway, South Korea, Turkey, and the United Kingdom.

For the undergraduate, graduate, and team categories, first-place winners received a cash prize of $500, second-place winners received a cash prize of $300, and third place received $250. The high school students received $100 for first place, $75 for second place, and $50 for third place.

AIAA student conferences give students an opportunity to present and publish their work in front of their peers and members of the industry. The AIAA Foundation sponsors student conferences in all seven AIAA regions each year. The Regional Student Conferences for Regions I-VI will take place in spring 2026.

2025 AIAA Region VII Student Conference Paper Winners

High School Category

- **1st Place:** Avighna Daruka, Krish Agrawal, and Ankit Bansal, Oslo International School, Norway, "CFD Analysis of Near-Field Exhaust Thermodynamics in Hydrogen-Fueled Jet Engines and Their Implications for Contrail Formation"
- **2nd Place:** Arif Emre Özden, Private Beştepe High School, Turkey, "Simulating Defect-Induced Local Modes and Phonon Dispersion in Two-Dimensional Materials with DFT"
- **3rd Place:** Helin Uluğtürken, Saint Michel French High School, Turkey, "Airfoil Performance Analysis: NACA 2412 vs 0012"

Undergraduate Category

- **1st Place:** Jordan Whittaker and Con Doolan, University of New South Wales Sydney, Australia, "Parametric Aerodynamic Study of the Properties of Leading-Edge Serrations on Wing Sections"
- **2nd Place:** Girisha Puri, University of Sydney, Australia, "Numerical and Experimental Investigation of a Passive Mixing Device in a Flight-Scale Hybrid Rocket Engine"
- **3rd Place:** Ishpreet Singh, University of New South Wales Canberra, Australian Defence Force Academy, Australia, "Flush Air Data System for a Blunt Wedge in Hypersonic Flow"

Graduate Category

- **1st Place Tie:** Seonghyeon Park, Seungshin Lee, and Jinyoung Suk, Chungnam National University, Republic of Korea, "Design and Experimental Validation of a Kalman Filter-based Double-Loop INDI Architecture for Robust Control of Multicopter UAVs"
- **1st Place Tie:** Vidit Bawa and Quentin Michalski, Royal Melbourne Institute of Technology, Australia, "An Experimental Framework for In-Flight Determination of Rocket Aerodynamic Drag"
- **3rd Place:** Nicoleta Railean, Fatime, Kuci, and Paul Kantzidis, Royal Melbourne Institute of Technology, Australia, "Numerical and Experimental Investigation of Small Ducted Propellers in Ground Effect"

Team Category

- **1st Place:** Allan Dong, Raymond Trinh, Xinwei Choot, and Benjamin Seow, University of Sydney, Australia, "Large Language Model-Enabled Multimodal UAV for Rescue"
- **2nd Place Tie:** Fei Fei Liu Webster, Giulia Mandarano, Karunakalage Dasitha Manulindu Karunaratne, and Abdulghani Mohamed, Royal Melbourne Institute of Technology, Australia, "Investigation of Passively Variable Pitch Blades with Ranging Pivot Locations on Rotor Load Imbalance"
- **2nd Place Tie:** Jolok Banarjee, Holyjith Paul Himel, Toymor Wafi Opul, MD Shajidul Islam Patwary, Tuhin Alahi Anny, and Shahrukh Khan, Aviation and Aerospace University, Bangladesh, "Sustainable Additive Manufacturing Using Recycle PET: Machine Development and Mechanical Evaluation"
- **3rd Place:** Mahi Uddin Ahmaad, Ashiquzzaman Sadi, Jolok Banarjee, Md Ahad Israq, and Saifur Rahman Bakaul, Aviation and Aerospace University, Bangladesh, "Structural Analysis and Material Selection for Wing of a Newly Designed Supersonic Fighter Aircraft"

AIAA Announces 2026 Sustained Service Awards Winners

AIAA has announced the winners of the 2026 Sustained Service Awards. The award recognizes sustained, significant service and contributions to AIAA by members of the Institute. The 2026 recipients are:

Melissa Carter, NASA Langley Research Center

For sustained leadership, service, and contributions to the Hampton Roads Section, Region I, and AIAA national as HRS officer, technical committee member, conference organizer, and conference session chair.

Carter became an AIAA student member at Penn State in 1997. She held many positions in the Hampton Roads Section, including Young Professional Committee Chair and Section Chair. She is a member of the Inlets, Nozzles, and Propulsion System Integration Technical Committee and served two years as Chair. Carter started working at NASA Langley Research Center as a co-op student in 1998, converted to a full-time employee in 2000, and is retiring in January 2026.

David Casbeer, Air Force Research Laboratory

For leadership advancing AIAA's focus on autonomy and intelligent systems in aerospace.

Casbeer, a 20-year member of AIAA, heads the UAV Cooperative and Intelligent Control Team at the Air Force Research Laboratory. His team works to develop enabling technology for autonomous UAVs, supporting future Air Force missions.

Wayne Hurwitz, Northrop Grumman Aeronautics Systems

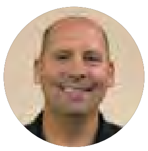
For sustained leadership and dedicated service to AIAA at the national level through significant contributions to Corporate Membership advocacy, the Air Breathing Propulsion TC, Propulsion & Energy Group, TAD leadership, and the Ethics Committee.

Hurwitz is the Northrop Grumman Fellow for Propulsion. He has served as a manager or IPT leader on a range of military aircraft programs. Hurwitz is an AIAA Associate Fellow and Deputy Director for the AIAA Propulsion and Energy (P&E) Group. A past chair of the AIAA Ethics Committee, he served as Director of the P&E Group and chair of the Air Breathing Propulsion Technical Committee. Hurwitz is the 2023 recipient of the Engineer's Council Jack Northrop Spirit of Innovation Award.

Elizabeth Lee-Rausch, NASA Langley Research Center

For sustained leadership, service, and contributions at the section and national levels as a Hampton Roads Section officer, Integration subcommittee leader, and journal associate editor.

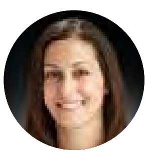
Lee-Rausch is the Chief Engineer for the AeroSciences Division at NASA Langley Research Center. She received her B.S. in aerospace engineering from Auburn University in 1987 and her M.S. in aeronautics and astronautics from Purdue University in 1992. Lee-Rausch has spent most of her career at Langley as a Research Engineer working on the application and validation of CFD tools for large-scale aerospace systems.



Michael Oppenheimer, Air Force Research Laboratory

For sustained leadership, service, and contributions to the Dayton/Cincinnati Section, Region III, and AIAA national.

Oppenheimer is a Senior Electronics Engineer at the Air Force Research Laboratory and an AIAA Associate Fellow. He has performed flight control research on reusable launch vehicles and flapping wing micro air vehicles, as well as development of control allocation techniques for multiple applications. Oppenheimer holds B.S. and M.S. degrees in electrical engineering from the University of Akron and a Ph.D. degree in electrical engineering from the Air Force Institute of Technology.



Kerri Phillips, Johns Hopkins University Applied Physics Laboratory

For sustained leadership and service through Technical, Ethics, and Public Policy Committees; the AIAA DEFENSE Forum Executive Steering Committee; and outreach at the section, regional, and national levels of AIAA.

Phillips serves as Program Area Manager for Threats and Intelligence in the National Security Space Mission Area at Johns Hopkins Applied Physics Laboratory. Formerly APL's Chief Scientist for Air and Missile Defense, she is an AIAA Associate Fellow and recognized expert in missile guidance and control. She was recently inducted into West Virginia University Mechanical, Materials and Aerospace Engineering's Academy of Distinguished Alumni for her technical and leadership achievements.

Joshua Rovey, University of Illinois

For sustained leadership, service, and contributions to the Illinois Section, Region III, and AIAA national.

Rovey is Professor of Aerospace Engineering at the University of Illinois and Director of the Illinois Space Grant Consortium. He is an Associate Fellow and a member of the Electric Propulsion Technical Committee and the Publications Committee. He spent several years as an associate editor of the *Journal of Propulsion and Power*.

Todd Treichel, Sierra Space

For exemplary leadership, dedicated service, and significant contributions to the Wisconsin Section, Region III, and the AIAA national organization.

Treichel is an Operations Manager at Sierra Space with over two decades of experience spanning quality, reliability, environmental testing, manufacturing, and design engineering. Notable spaceflight contributions include ISS payloads, Cygnus & HTV-X spacecraft, and Mars landers. Since founding the AIAA Rocket Science STEM short courses in 2010, Treichel has continued to lead this Wisconsin-based educational initiative. He is an AIAA Associate Fellow, Wisconsin Section chair, and recipient of the NASA Silver Achievement Medal.

AIAA Mid-Atlantic Section Conference Brings Students and Professionals Together

On 21 November, the AIAA Mid-Atlantic Section held its annual Young Professionals, Students, and Educators Conference at Johns Hopkins University Applied Physics Laboratory (JHUAPL). The conference — a flagship event for the section that represents parts of Maryland, Pennsylvania, and West Virginia — brings together high school, undergrad, and graduate students, as well as educators and young professionals from all over the East Coast and beyond. Presenters shared their research and networked with professionals from a wide variety of aerospace specialties and disciplines.

Attendees were welcomed with a morning keynote by Dennis Woodfork, mission area executive for National Security Space at the JHUAPL. During the event, attendees heard from AIAA Region I Director Kyle Zittle about the importance of professional networking events and presenting research, as well as AIAA's Director of Membership Brian Calvary on the value of involvement with a professional association throughout one's career lifetime. The day featured a live flight demonstration of Dragonfly, an autonomous relocatable rotorcraft lander that will assess the surface composition and chemistry of Saturn's moon Titan in the mid-2030s.

After concurrent presentations and touring the expo hall, the day concluded with a technical keynote from Jason Kalirai, the mission area executive for Space Formulation within the Space Exploration Sector at JHUAPL.

A Maryland high school participant shared that having the opportunity to attend was incredible. They didn't realize that there were spaces where students could actually be treated like professionals and get such a good headstart on the career they eventually want to pursue. They found the conference "really energizing."

Obituaries

AIAA Fellow Saric Died in April 2025

William S. Saric, Ph.D., NAE, died on 22 April 2025.

Saric graduated from the Illinois Institute of Technology with his Bachelors in Mechanical Engineering (1963). He earned his Masters in Mechanical Engineering from the University of New Mexico in 1965 and received his Ph.D. in Mechanics (1968) from the University of New Mexico. He was employed at Sandia National Laboratories in Albuquerque from 1963 to 1966 when he worked in various areas, including on high-velocity impact, magnetohydrodynamic entrance flows, and high-speed boundary-layer flows, and then again from 1968 to 1975 when he conducted research and advising on problems of reentry ablation, boundary-layer transition, transpiration cooling, heat transfer, and applied mathematics. It was at Sandia Labs where he was introduced to boundary-layer transition on reentry vehicles in 1972. After Sandia Labs, he was a faculty member at Virginia Tech (1975–1984), Arizona State (1984–2004), and Texas A&M (2005 until retirement in 2021).

A member of the National Academy of Engineering and a Distinguished and Chaired Professor at Texas A&M when he retired, Saric dedicated his academic career to 1) foundational theoretical and experimental understanding of boundary-layer instability, laminar-turbulent transition, and flow control including under flight-operational conditions, 2) establishing the standards for careful validation-quality experiments and flight research, and 3) freely educating and serving the international community and the next generation of researchers. Saric's scholarship profoundly contributed to new options for reduced fuel consumption in airborne systems, increased survivability in hypersonic systems for national defense, and the realization of low-boom configurations being explored for supersonic flight over land. He excelled both as a discoverer of new fundamental knowledge and as an innovator of new technology. Many have built upon his foundational insights and innovation.

Saric remarkably built and fully supported two major quiet tunnel facilities and a flight laboratory that provided the basis for the international community for numerous breakthroughs in transition mechanism identification, modeling, and control. 1) The Klebanoff-Saric Wind Tunnel was an internationally recognized ultra-low-noise wind tunnel within which the most sensitive boundary-layer stability experiments could be conducted. 2) The Mach 6 Quiet Tunnel was also an internationally recognized ultra-low-noise tunnel. Within this facility, Saric and his students conducted the first detailed hypersonic three-dimensional boundary-layer measurements. 3) The Flight Research Laboratory was a special facility with three aircraft devoted to foundational swept-wing transition and laminar flow control studies at transport unit Reynolds numbers and air-flow quality experiments.

A Class of 2005 AIAA Fellow, Saric was recognized with the 2003 AIAA Fluid Dynamics Award. He served on the *AIAA Journal* Advisory Board from 2010, and he had been an AIAA professional development instructor.

AIAA Honorary Fellow Bushnell Died in October 2025

Dennis M. Bushnell, NAE, died on 20 October 2025.

Bushnell graduated from the University of Connecticut in 1963 with an M.E degree and an M.S. from the University of Virginia in 1967, both in the field of Mechanical Engineering.

He retired from NASA Langley Research Center in 2023, after 60 years of service, the last 28 as its Chief Scientist. During his first 30 years, he conducted groundbreaking research in a wide range of areas, including viscous flow modeling and control, turbulent drag reduction, and hypersonic flight. He contributed to the Gemini, Apollo and Space Shuttle programs, oversaw technology for the National Aero-Space Plane, and conducted experiments and analysis of shock impingement interference heating on swept leading edges. The Viscous Flow Branch that he led pioneered the development of supersonic and hypersonic quiet tunnels, laminar-turbulent transition prediction methods, laminar flow control technology, and riblets for turbulent drag reduction. He also analyzed and published an extensive collection of the many initial disturbance fields that provide the initial conditions for and dictate the location of laminar-turbulent transition.

Bushnell inspired many to push the technological boundaries. In1988, he asked the following question of leading aerodynamicists and invited them to a workshop in spring 1989: "Is there a renaissance for the long-haul transport?" Bushnell's challenge was aimed at revolutionary advances in aircraft design. From the workshop came the blended wing body and the truss-braced wing concepts.

Bushnell had about 300 publications, 500 invited lectures, and 16 patents. For his service to the aerospace community, he was recognized with many awards including the 1975 AIAA Lawrence Sperry Award, 1991 AIAA Fluid and Plasma Dynamics Award, and several NASA awards including the Exceptional Scientific Achievement Medal and Outstanding Leadership Medal. He also received several lecture awards including the 1998 AIAA Dryden Lecture, 1998 RAeS Wilbur and Wright Lecture in 1998, 1994 ICAS Guggenheim Lecture, and Israel's 2006 Von Karman Lecture. He was a 1993 ASME Fellow, and 1995 Royal Aeronautics Society Fellow, and was elected a member of the U.S. National Academy of Engineering in 1998.

Bushnell served AIAA in many capacities, including as a member of the *AIAA Journal* Editorial Advisory Board, Fluid Dynamics Technical Committee, and Chair of the Technical Program Committee and Session Chair for over 20 AIAA conferences. He was elected AIAA Fellow in 1988. He was elevated to AIAA Honorary Fellow status in 2016.

AIAA Fellow Hauck Died in November 2025

Former NASA astronaut **Rick Hauck**, who flew on three Space Shuttle missions, died on 8 November. He was 84 years old.

Hauck received a bachelor's degree in physics from Tufts University in 1962 and a master's in nuclear engineering from MIT in 1966. He earned his wings in 1968 and graduated from the U.S. Naval Test Pilot School in 1971, before flying 114 combat and combat support missions in Southeast Asia and later becoming the Navy's lead test pilot for the carrier suitability of the F-14 Tomcat.

Hauck was chosen to become a NASA astronaut in 1978 with the first 35 candidates selected for the Space Shuttle program. He was on the support crews for STS-1 and STS-2, serving in Mission Control as a reentry capcom for both.

His first Space Shuttle mission assignment was as pilot of STS-7. His second mission was as commander for the second mission of *Discovery* on mission STS-51-A. Before his third Space Shuttle mission, Hauck worked at NASA Headquarters, where he was appointed associate administrator for external relations, advising NASA Administrator James Fletcher.

After the *Challenger* tragedy, Hauck supported the Return to Flight preparations by reviewing requirements at the Johnson Space Center in Houston. In 1988, he and crewmates lifted off on *Discovery*, which had redesigned solid rocket boosters and other safety-driven improvements. During the STS-26 mission, the astronauts deployed a Tracking and Data Relay Satellite and paid tribute to *Challenger*'s fallen crew.

In March 1989, he resigned from NASA and became director of the Navy space systems division in the Office of the Chief of Naval Operations before leaving military active duty in June 1990 with the rank of captain.

In October 1990, Hauck became president and chief operating officer of AXA Space. From 1993 until his retirement in March 2005, he was the company's CEO.

Hauck was a Fellow of AIAA and the Society of Experimental Test Pilots. Besides receiving NASA's distinguished service, outstanding leadership, and space flight medals, he was also recognized with the Fédération Aéronautique Internationale's (FAI) Yuri Gagarin Gold Medal and the 1989 AIAA Haley Space Flight Award.

View complete obituaries

What we can learn from air disaster TV shows

BY AMANDA SIMPSON | simpson.amanda.r@gmail.com

Amanda Simpson is a consultant, a former U.S. deputy assistant secretary of defense for operational energy, and a former head of research and technology at Airbus Americas, where she led sustainability efforts. An AIAA fellow, she's a licensed pilot and certified flight instructor.

There are several shows I will watch any time I see them, and near the top of the list is "Mayday," the award-winning Canadian documentary series also known as "Air Crash Investigations."

Each of the nearly 300 episodes reenacts catastrophic incidents in aviation history and provides insight into what went wrong, how it could have been prevented and what changes the industry made as a result. Circumstances range from hijackings to disgruntled employees, suicides, onboard fires and more. There are collisions, such as the Cerritos Air Disaster (season 4, episode 7) and weather-initiated accidents, such as the wind shear event at Dallas-Fort Worth (season 5, episode 1).

Although these episodes are geared toward a general audience, they also contain lessons for aviation professionals, including aerospace engineers. The root causes of the catastrophic incidents can be grouped into three main categories: mechanical failures, maintenance mistakes and pilot errors. In the end, however, nearly all can be traced back to human choices.

Mechanical failures

Because airplanes are designed with safety as the foremost priority, such failures are quite rare and difficult to predict. Multiple episodes depict a system failure due to fatigue or other degradation and, through reenactments, illustrate how that leaves the crew members fighting for the survival of the aircraft and the lives on board — including their own.

These might seem like straightforward technical issues, but the true root cause can almost always be traced back to a human decision. Consider the "Turning Point" episode from season 11, about the catastrophic failure of a Boeing 747-400's lower rudder power control module (PCM). A small fracture in the PCM's metal housing resulted in full-scale deflection of the lower half of the rudder, inducing a violent bank to the left of nearly 40 degrees. Through herculean efforts, the flight crew was able to regain control, divert and safely land the aircraft.

Investigators learned that although the PCM had been routinely inspected, there was no inspection guidance or requirement for the manifold housing. Repeated motions of the PCM caused the fatigue cracks that eventually gave way on a part that was expected to outlive the aircraft itself. In other words, the designer and manufacturer made assumptions that proved erroneous.

The lesson for aviation professionals? It is one thing to learn from the mistakes of the past, but our challenge is to use those experiences to help predict the future. Designers and engineers must not give in to assumptions, but rather try to predict the unpredictable.

Another subset of mechanical failures is design issues that have resulted in loss of life. A season 5 episode revolved around multiple DC-10s that experienced explosive decompression, caused by a door design meant to allow more cargo to be loaded. Instead, a crash occurred when the latches failed on the outward opening cargo door. The first failure led to a redesign, yet the problem happened again and brought down a second aircraft. In season 4, we are shown three Boeing 737-200 aircraft that over a five-year period in the 1990s suffered full deflection of their rudders without input from the pilots. This caused at least 150 deaths due to a design flaw with the rudder control system before one flight crew managed a successful landing, preserving the evidence that revealed the cause.

Maintenance mistakes

Another common cause seen in the show is poor maintenance or botched practices. In season 11, technicians overlooked reinstalling the screws that held the leading edge in place on a horizontal stabilizer. Signoffs were incomplete and inspections were missed. The leading edge separated from the aircraft while on approach to land, rendering it completely unflyable.

In season 2, a pilot was partially sucked out a cockpit window because a maintenance worker installed incorrectly sized bolts holding the cockpit window in place. And in season 23, a flight crew battled with an airliner where the aileron cables had been installed backward. Each of these maintenance errors was the last link in an error chain that started with the design, documentation, instructions and execution of the repair.

The lesson is that aviation professionals should not rely on someone else breaking the error chain, but must remain diligent at every step of the process.

Flight crew error

Mistakes by the flight crew or pilots appear to be the most common cause, as determined by the investigator reenactors. Several episodes deal with the flight crew's misinterpretation of cockpit instruments or displays (season 6, episode 3) or distractions when interfacing with the aircraft's systems or autopilot (season 9, episode 7).

There could be any number of lessons here: How can designers and aerospace engineers plan for errors that pilots make? Can there be better displays and machine-human interfaces so pilots are better aware of unusual situations and how to appropriately respond? With commercial piloting offering hours and months of consistently expected operations punctuated by moments of unanticipated events, can there be better training through advanced simulation to keep pilots prepared for the unexpected? Or does adding additional automation to assist an overwhelmed flight crew or taking the human out of the flight deck become the answer?

For another opinion, I turned to Robert Sumwalt, former chairman of the National Transportation Safety Board and executive director of the Boeing Center for Aviation and Aerospace Study at Embry-Riddle Aeronautical University. "People sometimes ask me what percentage of accidents are attributed to human error," he said. "I reply that nearly 100% of accidents I've studied — and there are literally hundreds — have human error somewhere in the system."

"It may be an error of a front-line operator, such as a pilot, technician, or air traffic controller, but if we dig far enough, we may find those errors have roots tracing back further in the system, such as a design or engineering issue that wasn't detected until the crash investigation," he continued. "There is great learning value from learning from the mistakes of others, and that learning can transpire by watching a well-produced documentary."

The aerospace industry is poised to enter a period where new aircraft will be designed and new space transportation systems will be developed. Passenger safety will depend on quality design, development, manufacturing, maintenance and operation. The tools used and attitudes employed will determine if we have learned from the past to expect the unexpected. ★

> "It is one thing to learn from the mistakes of the past, but our challenge is to use those experiences to help predict the future. Designers and engineers must not give in to assumptions, but rather try to predict the unpredictable."

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A different way of viewing China's space ambitions

BY MORIBA JAH | moriba@utexas.edu

When I visited China several years ago, I met with an engineer from the Chinese Academy of Sciences to discuss the technological advances of the West. Calling the Chinese "the descendants of dragons," he said "we have awakened." In that moment, I saw China's space program as not just a national project, but also a civilizational act of remembrance.

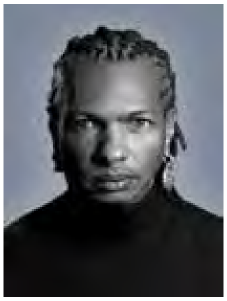
I was there teaching courses on statistical orbit determination at the Beijing Institute of Technology and at Shanghai Jiao Tong University. Between lectures, my hosts took me to a rural village near Shanghai called Zhujiajiao, also referred to as the "Venice of Shanghai," where houses were packed along waterways and incense drifted from small temples.

One of my guides spoke candidly about the impact of the decades of extraction and colonialism by the West, chiefly the U.S., U.K. and Europe. He spoke too of what he perceived as hypocrisy by nations that once divided his homeland and now lecture it about ethics, such as military interventions and human rights standards.

China's long history shapes its behavior in ways Americans often fail to grasp. For instance, the Chinese people remember historical humiliations: the ports forced open by British gunboats, the unequal treaties, the racial exclusion in Western lands. They remember the long arc of Chinese experience in America: the mid-19th-century labor migrations that brought men to blast tunnels through the Sierra Nevada for the Transcontinental Railroad, and the Page Act and Chinese Exclusion Act that barred their families and stripped them of any path to citizenship. Chinese communities were blamed for economic downturns in the 1870s and 1880s, targeted during the Rock Springs and Los Angeles massacres, quarantined during smallpox and plague outbreaks in San Francisco, and later treated with suspicion during the Red Scare. That history burns beneath Chinese policy choices.

What became obvious to me is that China's global reach is about protection — of its people, culture and lineage. To watch Chinese rockets and spacecraft ascend into orbit today is to witness a culture performing self-repair in real time. The West calls it competition; Beijing calls it rejuvenation. In the mythic lexicon of Chinese identity, the dragon symbolizes harmony, intelligence and cosmic order. To awaken it is to restore equilibrium after chaos. For a civilization that still carries the scars of what's dubbed the "Century of Humiliation" — the period from the mid-1800s Opium Wars through Japan's wartime occupation — space is not simply the next frontier. It is the stage for redemption.

When Chinese engineers talk about reaching the moon or building a station in lunar orbit, it's clear they're thinking in terms of decades or even centuries. Yet government officials and policy experts in Washington often frame every milestone as a revival of the Cold War space race, a contest for strategic advantage, another chapter in the story of American preeminence under threat.



Moriba Jah is an astrodynamicist, space environmentalist and professor of aerospace engineering and engineering mechanics at the University of Texas at Austin. An AIAA fellow and MacArthur fellow, he's also chief scientist of startup Privateer.

That framing flattens a far older story. China's rise in space is propelled by two intertwined forces. Culturally, it springs from a five-millennia worldview that never severed the link between humanity and the sky, seeing order in heaven as inseparable from harmony on Earth. Politically, it channels the memory of subjugation into a project of national self-possession. President Xi Jinping has made this explicit by tying space exploration to what has been called "the great rejuvenation of the Chinese nation," a vision built on transcending the Century of Humiliation.

Yet the moral geometry of restoration bends easily toward domination. The Belt and Road Initiative's growing presence across the Global South is often described as cooperation, but it's not kinship. China offers satellites and launch services to developing nations, but the prosperity often flows one way. In Kenya, Zambia, Peru and Sri Lanka, residents have protested land seizures, debt-heavy deals, unsafe mining conditions and ports leased for generations, arguing that these Chinese-backed projects echo older patterns in which outsiders extracted wealth while locals absorbed the harm.

Even in China, the cost of this awakening is measured in poisoned rivers and smog-filled skylines. The country that once regarded harmony with nature as sacred has become one of the planet's most prolific polluters.

What matters now is not which nation launches more rockets, but the values guiding those rockets once they leave the ground. China's space program is shaped by a long memory, a desire for restoration, order and national coherence. America's is shaped by frontier myth, commercial ingenuity and a belief that disruption itself is virtue. These orientations produce different architectures, different governance instincts and different definitions of responsibility.

In a world of shared orbits, these value systems do not remain abstract. A China that prizes central control will favor tightly managed constellations, state-centric navigation systems and a closed standard-setting process. A United States that elevates market dynamism will produce congested skies, proliferated satellites and norms shaped not by treaties but by quarterly earnings. One leans toward strategic stability, the other toward rapid iteration. Each creates a future that complicates the other.

The divergence becomes most consequential in crises — a collision in low-Earth orbit, a misinterpreted maneuver, a debris cascade. A governance framework built on central authority will interpret ambiguity through suspicion; one built on commercial freedom may fail to impose guardrails before it's too late. Without a shared ethic, uncertainty becomes escalation. The danger is not that one system triumphs, but that both drift into a world where coordination is impossible.

This is why the story of values is the story of outcome. If we continue to treat space as a proving ground for old identities — China seeking rejuvenation, America chasing reinvention — we inherit orbits shaped by rivalry instead of reciprocity. But if either side can step beyond its reflexes, the future of space changes: Debris becomes a managed commons instead of a tragedy, constellations become infrastructure instead of hazard, and exploration becomes an act of stewardship rather than projection. ★

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LOOKING BACK

100, 75, 50, 25 YEARS AGO IN JANUARY–MARCH

COMPILED BY FRANK H. WINTER AND ROBERT VAN DER LINDEN

1926

Feb. 15 The first contract air mail service in the U.S. begins with a flight by Ford Air Transport. A party of observers that includes Henry Ford watches the Ford Stout all-metal monoplane take to the air in Dearborn, Michigan. The new service will connect Detroit with Chicago and Cleveland. **Aviation**, March 1, 1926, p. 292.

1 **March 16** Robert H. Goddard launches the world's first liquid-fueled rocket from Auburn, Massachusetts. The tiny design — propelled by liquid oxygen and gasoline — flies for 2.5 seconds, climbing to 12.5 meters before it arches and then plunges into the snowy ground 56 m away. Goddard, his wife, Esther, and his two assistants are the only witnesses, and the extremely secretive Goddard did not publicly reveal this achievement until a full decade later. Eugene Emme, **NASA Aeronautics and Astronautics, 1915-1960**. Michael Neufeld, **"Robert Goddard and the First Liquid-Propellant Rocket,"** March 16, 2016.

1951

Jan. 30 Bell Aircraft Corp. begins construction of a $3 million helicopter plant in Fort Worth, Texas. This will become the center of all Bell helicopter production. A.J. Pelletier, **Bell Aircraft Since 1935**, p. 15. **The Aircraft Year Book, 1951**, p. 78.

Feb. 10 The Douglas DC-6B, a lengthened passenger version of the DC-6A and DC-6C cargo aircraft, makes its first flight. This 32-meter-long variant, which proves to be one of the most successful piston-engine transports ever built, can seat up to 102 passengers and has a range of 2,610 nautical miles (4,830 kilometers). Douglas produces nearly 300 before ending DC-6 production in 1958. Kenneth Munson, **Airliners Since 1946**, pp. 123-124.

2 **March 15** Boeing test pilots refuel a Boeing B-47A Stratojet medium bomber for the first time, via a KC-97A tanker equipped with a refueling boom. This method of air-to-air refueling becomes standard operating procedure for U.S. Strategic Air Command. Later, the difficulties of operating propeller-driven tankers alongside jet-propelled fighters and bombers prompt Boeing to accelerate development of jet tankers, leading to the KC-135 Stratotanker and eventually the Boeing 707 airliner. USAF, **A Chronology of American Aerospace Events**, p. 59.

1976

3 **Jan. 13** The V.M. Blanco, the largest optical telescope in the Southern Hemisphere, begins operations on a mountaintop about 500 kilometers north of Santiago, Chile. The 13.7-meter-long telescope's steerable portion weighs 300 tons but is so delicately balanced that one person can move it by hand. The telescope is in the new Cerro Tololo Inter-American Observatory, which is run under contract by the U.S.'s National Science Foundation in cooperation with the University of Chile at Santiago and others. **National Science Foundation Release** PR 76-4.

Jan. 17 A Delta rocket launches the Communications Technology Satellite, designed jointly by U.S. and Canadian technicians, from Cape Canaveral, Florida. CTS is the world's most powerful communications satellite and the result of a five-year program that aims to demonstrate new technology, conduct communications technological experiments and develop new communications methodology in conjunction with ground-based components. **New York Times**, Jan. 30, 1976, p. C11, and **NASA News Releases** 76-9 and 75-316.

Feb. 5 NASA's Marshall Space Flight Center announces that the historic Redstone test site, largely unused since the last Redstone missile test firing in 1961, is to be restored to its original appearance as an exhibit for visitors during the U.S. bicentennial celebrations throughout 1976. In January 1958, a modified Redstone launched Explorer 1, the first U.S. satellite. Another modified Redstone powered Alan Shepard's May 1961 trip to orbit, the first U.S. crewed spaceflight. **Marshall Space Flight Center Release** 76-32.

4 **Feb. 29** Aviation pioneer Grover Loening, the first person to earn an aeronautical degree from a U.S. university, dies at 87. A member of Orville Wright's early design team, Loening in 1913 became the manager of the Wright factory in Dayton, Ohio, before his appointment in 1914 as chief aeronautical engineer of the U.S. Army Signal Corps. His later achievements include pioneering the first steel-frame aircraft in the U.S. and helping establish Pan Am Airways and Grumman Aircraft Engineering Corp. **Washington Star**, March 2, 1976, p. B-5.

March 16 The 50th anniversary of Robert Goddard's launch of the world's first liquid-propellant rocket is commemorated with a reenactment at the launching site, on what is now the Pakachoag Golf Course, near the city of Worcester, Massachussetts. Apollo 17 astronaut Eugene Cernan — the last person to walk on the surface of the moon — symbolically lights a non-flyable replica of the 1926 rocket specially built for the occasion. During the three-day event, there is also an exhibit on Goddard's life and work at the Museum of Worcester and a rocket display at the Worcester Polytechnic Institute at Auburn, where he studied physics prior to receiving his Ph.D. from Clark University in Worcester. **Washington Post,** March 17, 1976, p. C-2; **Astronautics & Aeronautics**, October 1976, p. 66; Michael Kernan, "50th Anniversary of Step Toward Space," **Smithsonian Magazine**, March 1976, pp. 76-80.

2001

During January Air Canada begins a trial of in-flight email and internet services for its frequent flyers. **Flight International**, Jan. 23-29, 2001, p. 16.

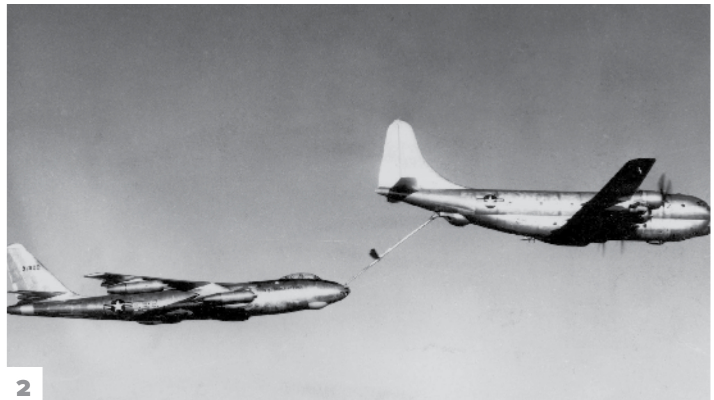
Feb. 7 The first Iranian-built Antonov An-140, designated IrAn-140, makes its inaugural flight from the Iranian Aviation factory near Isfahan. The aircraft, assembled from a kit produced in Kharkov, Ukraine, is also claimed to be the first commercial airliner produced in Iran. **Flight International**, Feb. 20-26, 2001, p. 13.

5 **Feb. 12** NASA's NEAR (Near Earth Asteroid Rendezvous) Shoemaker probe becomes the first human-made object to land on an asteroid. The soft landing upon the asteroid Eros, some 355 million kilometers from Earth, was not part of the original mission, which simply called for Shoemaker to orbit the asteroid. **Flight International**, Feb. 20-26, 2001, p. 33.

6 **March 23** After 15 years in orbit, the Mir space station reenters the atmosphere. The controlled deorbit maneuver directs all surviving debris into the Pacific Ocean some 2,700 kilometers east of New Zealand. Mir was launched in February 1986 by the former Soviet Union, and over its lifetime made 86,320 orbits and hosted 104 visitors who conducted 23,000 experiments and 140 spacewalks. **Flight International**, March 27-April 2, 2001, p. 7.

LOOKING BACK+
MORE ENTRIES AVAILABLE ON THE WEBSITE


1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Eden Abeselom Habteslasie

A high school passion for calculus led Eden to her current role in the space sector. As a space engineer at the Space Science and Geospatial Institute in Ethiopia, her work spans systems engineering, avionics systems, and attitude and orbit control systems. — *Marjorie Censer*

What's your aerospace origin story? ▶ I'm passionate and have always been fascinated by the engineering that goes into the machines that fly into space. It took me from a degree in electrical engineering to a master's degree in space engineering. Growing up in Ethiopia, where the aerospace sector is still in its early stages of development, has driven me to contribute to its growth and become a pioneer in the field. To build practical experience, I participated in international aerospace research projects, which have helped me strengthen my technical skills and further solidified my interest in the area.

Favorite thing about your job? ▶ How it allows me to be part of research in enabling technology for spaceflights and exploration. It's fascinating to contribute to technology that will leave Earth. Being part of new findings in space technology and exploring innovation is a fulfilling experience; being part of a global community pushing the boundaries of space technology inspires me. Furthermore, it provides an opportunity to collaborate with international professionals and experts in the aerospace sector.

What motivates you? ▶ The significant impact of satellites on national development. As a developing country, Ethiopia's situation makes it quite challenging to have access to and develop space capabilities. However, it is still necessary. Hence, I decided to pursue a master's in space engineering to help strengthen the space sector and make a positive impact in Ethiopia and potentially across Africa in the years to come.

What tech outside your field fascinates you? ▶ I'm curious about the influence of AI on different industries. What fascinates me the most is envisioning AI as the next step in spacecraft design, planning missions, and executing operations without human beings.

What will the world look like in 2050? ▶ Humanity will be closer to becoming a multiplanetary species, meaning progress in establishing sustainable habitats beyond Earth. Aerospace technology will be more advanced and accessible, enabling even the most emerging nations to have stronger, more independent space capabilities. I envision a future in which space plays an active part in global development and in everyday life. ★

MORE ABOUT EDEN

AIAA CONNECTION: A member of the 2025 AIAA Ascendants cohort, she presented at the July 2025 conference in Las Vegas, which she called "the coolest experience." "It allows me to collaborate and network with aerospace professionals and experts, and it gives me a chance to present my work and publish an op-ed on the ASCEND event website."

Her Ascendants paper, "Space Debris as a Barrier to Sustainable Space Development in Emerging Nations," concluded that "debris represents not only a technical hurdle but also a moral and geopolitical challenge. Without urgent, equitable action, emerging nations will bear the brunt of a crisis they did not create, stifling their potential to advance climate monitoring, connectivity, and scientific discovery."

EDUCATION: Bachelor's degree in electrical and computer engineering, Debre Birhan University, 2019; Master's degree in space engineering, Addis Ababa Science and Technology University, 2024.

GROWTH PLANS: She sees a bright future for the Ethiopian aerospace industry: "This field is still growing, and a lot of experts, students, and professionals are also engaged in this sector. My friends from high school and university always tell me, 'This was your passion, and you made it happen.'"