JULY-SEPTEMBER 2025

AEROSPACE AMERICA

Eyes IN THE skies

How small drones could make a big difference against wildfires. PAGE 24

INSIDE THE ISSUE:

AIAA

24-29 Fighting fire with drones

From early detection to expanded monitoring, we explore the ways that these small aircraft can help combat tomorrow's wildfires.

By Jen Kirby

The 2021 Dixie Fire in Northern California was, at the time, the second largest the state had ever experienced. This drone was among those flown by the U.S. National Park Service and other organizations to monitor and combat the fire.
National Park Service/Joe Suarez

18 The Big Question

Will electric air taxis really change the way we travel? Six experts give their views.

By Paul Brinkmann

30 Robert Goddard's other ideas

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By Roger Launius and Jonathan Coopersmith

34 Life-saving technology

Of all the technologies required to operate a commercial space station, those that keep humans alive are the most crucial — and challenging.

By Jonathan O'Callaghan

DEPARTMENTS

Aerospace America presents readers with independently produced news and feature articles and a rich variety of opinions relevant to the future of aerospace. The views expressed in these pages are not necessarily those of our publisher, AIAA.

ON THE COVER: Our partner THOR Design Studio created this firefighting illustration with MidJourney, an artificial intelligence design tool, and refined it in Adobe Photoshop.

EDITOR'S NOTEBOOK

Looking to the past as we chart our future

Like many of you, I've been closely following the White House's fiscal 2026 budget proposal and the potential impacts to NASA and other agencies that must figure out how to make do with much less money. While members of Congress will have their own ideas about which research and missions are worth preserving — as the saying goes, "the president proposes, the Congress disposes" — it seems inevitable that there will be some cuts. For those of you who have devoted years if not decades to these projects and programs, I know it is heartbreaking to contemplate saying goodbye. If you have ideas about stories we should pursue or want to share your personal experiences, please reach out.

I hope the stories in these pages and on the revamped Aerospace America website continue to inspire and motivate you. Our Looking Back history column [page 70] is always one of my favorites because of the many hidden gems — milestones I'd forgotten about or weren't aware of that played a part in bringing the aerospace industry to where it is today. I'd like to highlight a few entries that share some connection with other stories in this issue: the 1925 crash of the USS Shenandoah airship and the spaceflights in the 2000s to assemble the International Space Station.

I've often marveled at the circular nature of this industry, in that sometimes it feels like there are no "new" problems, just variations of the same ones. See, for example, our feature story on developing life support technology for the future commercial space stations [page 34]. These aspiring operators are grappling with many of the same questions and challenges that NASA did for ISS — which itself is coming up on 25 years of continuous human presence later this year. NASA's commercial LEO program was one of the few to get an increase in the fiscal 2026 proposal, but as anyone involved in technology development knows all too well, more funding isn't always enough to guarantee success.

On the topic of air travel, the Shenandoah crash reminded me of the high standards for aircraft designers and builders, particularly when the most precious of cargo will be aboard. Safety continues to be a driving force today, as you can see from our Engineering Notebook about the next steps in Airbus' quest to develop a hydrogen airliner [page 14], as well as this month's Big Question on the emerging advanced air mobility market [page 18].

Speaking of history, I'd be remiss not to also direct you to the first article of our three-part Goddard Centennial Series [page 30], which kicks off our coverage of next year's anniversary of the first liquid-fueled rocket launch. One could reasonably argue that without that three-second flight on March 16, 1926, we wouldn't be having discussions today about sending humans to Mars — much less in the next decade. For this series, historians Roger Launius and Jonathan Coopersmith will unearth facts and details about Robert Goddard that you might not know and the role they played in his technical achievements. I had a blast editing the first article, which describes the methodical approach that Goddard took in assessing various methods for reaching orbit before he determined that liquid propulsion was the most feasible and practical. I was reminded of the same scientific method we still rely on today.

These past endeavors remind me that change rarely comes without struggle, even if the end result is positive. But I remain hopeful that the human spirit is capable of rising to any challenge, of meeting any moment, no matter how challenging — so long as we never forget what we are fighting for. ★

Cat Hofacker

▲ NASA astronaut Anne McClain took these photographs of lightning from the International Space Station in late May.
NASA

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FOR THE RECORD: From our inbox

Adapting Homo sapiens for the stars

John McKean, an AIAA senior member in Iowa, agreed with the central point of Moriba Jah's January column ["Homo sapiens: making us suited for the stars"] but believes that Jah "missed a few important considerations":

"First, evolution is not done with us. If we can develop sustainable environments on the Moon and Mars, then the Law of Natural Selection will determine if a Homo luna or Homo martian will evolve. Second, he did not even mention Venus that has near Earth gravity. Terraforming Mars or Venus may take 10,000 years or more, but that's not long in terms of geological time. We could start that process with current technology, and help speed it on its way as it develops. Until we develop a sustainable way to get out of our gravity well (possibly a space elevator), most exploration of space will continue with unmanned probes. And it's possible that it would be easier to develop a space elevator on the Moon or Mars, and use those lessons back on Earth.

"Since the beginning of the Space Age, it has always been imagined that some form of artificial gravity would be developed for Earth orbit or deep space human missions. So developing that technology may also be a part of resolving this problem."

More advice for Boeing

After reading the April-June Big Question ["What advice would you give Boeing?"], James Carter, an AIAA associate fellow in South Carolina, sent us his own answer:

"There is merit to these suggestions [given by the four experts]; however, a more fundamental, impactful approach would be for Boeing's leaders to engage the employees to use the process improvement tools of lean manufacturing. These tools were largely invented by Toyota and resulted in the manufacture of cars with zero defects. Examples of these tools include: workplace organization (5S), standard work, total productive maintenance, mistake-proofing, and setup time reduction. All Toyota employees have knowledge and use these tools to eliminate waste in the manufacturing process. The Toyota Production System, now generally referred to as 'lean manufacturing,' has become a 'way of life' in many companies worldwide and has had a major impact on product quality, productivity, and on-time delivery. I helped lead this process at Pratt & Whitney in the late 1990s. This operating system is called ACE, Achieving Competitive Excellence."

CORRECTIONS:

The May 24, 2000, entry of Looking Back in the April-June issue named the incorrect payload aboard the inaugural Atlas III launch. The rocket carried the Eutelsat W4 satellite. Also, the entry for June 25, 2000, listed the incorrect rocket. It was the Long March 3, not the 3A, that conducted its final flight on this day. The online versions of both entries have been updated.

LET US HEAR FROM YOU

Send letters of no more than 250 words to letters@aerospaceamerica.org. Your letter must refer to a specific article and include your name, address and phone number. (Your address and phone number won't be published.)

ASCEND 2026: Building a Space Week in Washington, D.C.

Clay Mowry
AIAA CEO

The space industry has reached an inflection point. We are witnessing unprecedented growth in commercial space activity, accelerated national security priorities, international realignment in civil space programs, and a new generation of professionals entering the field. We need a technology-focused forum that matches the complexity and ambition of our moment. That's exactly what we're creating with ASCEND 2026.

Working with other leading space nonprofit organizations, we're reimagining how the space community comes together to tackle our most pressing challenges. ASCEND 2026 is designed for the future of space—incorporating sectors like biotechnology, venture capital, lunar mining, tourism, and other private enterprises with the traditional players—to make space commerce commonplace.

For the first time, we're creating a Space Week in Washington, D.C., that brings together every sector of our ecosystem. We will focus on collaborative learning, policy dialogue, and next generation conversations while deploying AIAA's hallmark of technical depth in paper presentations and sessions.

Moving ASCEND to Washington, D.C., in May 2026, takes our vision to the next level. We are creating a gravitational center that pulls together the full spectrum of space stakeholders in the city where policy, funding, and strategic decisions are made. Proximity to government decision makers will be vital. When commercial space executives, military and government leaders, young professionals, and international partners can engage in substantive dialogue over the course of a week, the potential for outcomes multiplies exponentially.

The new event partners bring decades of experience and deep expertise.

- As our premier event partner, Commercial Space Federation (CSF) brings unparalleled expertise in policy discussions that shape how we regulate and support commercial space activities.
- ISS National Laboratory brings a critical dimension through their leadership in space-based research and development, as well as engagement from the investment community.
- Space Force Association (SFA) enhances the mission-critical focus on national security space—a sector that becomes more essential each day as we face growing threats in the space domain.
- Space Generation Advisory Council (SGAC) delivers the promise of the future. Their signature fast-paced programming will create an environment where established industry leaders can learn from the next generation while inspiring young professionals to tackle our biggest challenges.

What makes this overall collaboration truly transformative is the timing. We're entering a period where the boundaries between commercial, civil, and national security space are increasingly blurred. Today's startup could be tomorrow's prime contractor. Today's research project could become the next operational capability. Today's student could be leading the first human mission to Mars.

The further integration of these space community sectors reflects a fundamental truth about our industry—the challenges we face require interdisciplinary solutions. No single sector has all the answers. By bringing together policymakers, entrepreneurs, researchers, warfighters, and students, ASCEND creates the conditions for breakthrough innovations that none of us could achieve alone.

The format itself reflects our commitment to driving real results. ASCEND has become known for a visionary agenda, inspiring speakers, and a community spirit that welcomes everyone who is committed to space. Beyond presentations and panels, ASCEND delivers collaborative sessions, hands-on workshops, and learning opportunities designed to forge the partnerships that will accelerate our off-world future.

Looking ahead to next year, I see ASCEND as more than an event—it's a catalyst for the space economy's next phase. We're creating a new model for how the space community collaborates, innovates, and solves problems together. As we anticipate what's to come, we are especially grateful to Lockheed Martin for their long-time involvement as ASCEND's Founding Sponsor.

I encourage every corner of our community to join us. Whether you're working on breakthrough propulsion technologies, revolutionary microgravity research, impactful space policies, or cutting-edge national security applications—ASCEND 2026 is where your work will have maximum impact.

We're building something unprecedented—a Space Week that reflects the full complexity, ambition, and promise of our community. Accelerating our off-world future isn't just about reaching new destinations—it's about creating new ways of working together to get there. ASCEND 2026 will show the world what's possible when the entire space ecosystem comes together.

The countdown starts now. ★

AERO PUZZLER

‘Nothin’ but blue skies,’ but why?

ENCORE

We ran this question in December 2023 and couldn’t believe no one got it right. So let’s try this again.

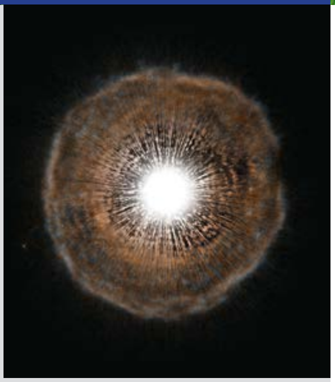
Q: True or false and why: On a sunny day, the blue sky overhead results from the same principle of molecular absorption that exoplanet researchers rely on to determine the atmospheric composition of planets too dim to be imaged even by the James Webb Space Telescope.

SEND A RESPONSE OF UP TO 250 WORDS
to aeropuzzler@aerospaceamerica.org. By responding, you are committing that the thoughts and words are your own and were not created with the aid of artificial intelligence. DEADLINE: noon Eastern Sept. 5.

Scan to get a head start on the next AeroPuzzler

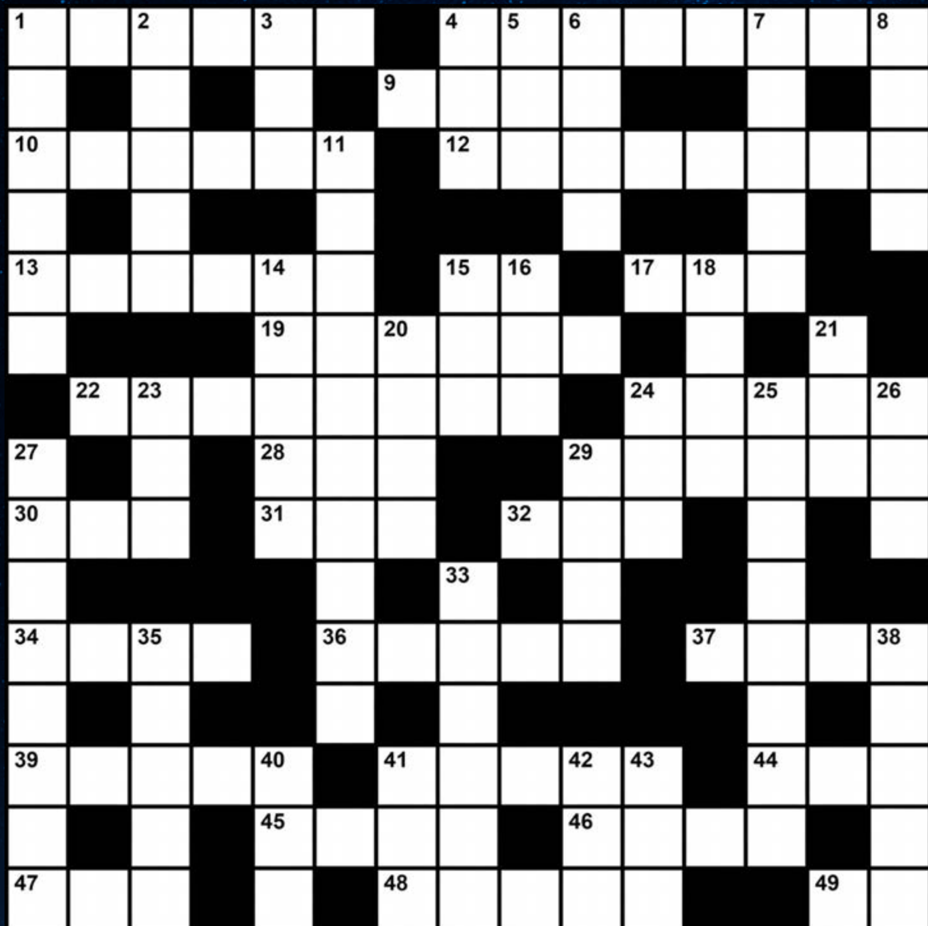
FROM THE APRIL-JUNE ISSUE

MYSTERIOUS OBJECT:



We asked you to identify the cosmic feature pictured at right and explain how such features figure into research related to the expanding universe. We didn’t receive any responses, so we asked astronomer Frank Summers from the Space Telescope Science Institute in Baltimore to weigh in:

“The object is a red giant star observed by the Hubble Space Telescope. Red giants are extremely big and extremely luminous, such that the brightest can be observed in other galaxies. Importantly, the brightest red giants have the same absolute luminosity. [Note: absolute luminosity measures brightness as would be seen from a standard distance, while apparent luminosity measures brightness as seen from Earth.] Astronomers can study a galaxy’s stars to measure the apparent luminosity for the “tip of the red giant branch” (i.e., the maximum red giant brightness). By comparing the apparent luminosity to the known absolute luminosity, they determine a distance to the galaxy. Plotting those galaxy distances versus galaxy redshifts (measured using spectra) is the Hubble Diagram. The slope of a linear fit to that distance vs redshift plot is the Hubble parameter, which measures the expansion rate of the universe.”



CROSS WORD

Test your knowledge, then find the answers online.

Across

1 NASA program that concluded 53 years ago in December

4 Blue Origin wants to stick this landing

9 Black Hawk, for example

10 Astroscale and other companies want to remove this from orbit

12 One reason an aircraft might not be able to fit at a gate

13 Not damaged but _______

15 Quality of Starship livestreams, abbr.

17 She starred in the sci-fi film "Arrival": ___ Adams

19 In "Top Gun," Maverick experienced this effect of extreme flight

22 Replicate the conditions, behavior or appearance of something in a controlled or artificial environment

24 DARPA program to retrofit existing aircraft for autonomous flight

28 Method that provides unambiguous range measurements to mm precision, abbr.

29 Rille on the moon, but ______ on Earth

30 The Apollo 11 landing appeared in grainy black and white on these

31 Secure

32 Par___

34 NASA has a low tolerance for this

36 The famous features on Io do this frequently

37 Before NASA there was _____

39 Gas giants contain these kinds of elements

41 These Hubble arrays had to be repaired multiple times

44 Pilots check this gauge to determine air-to-fuel ratio

45 The acronym of this NASA advisory group doubles as a command

46 Anakin Skywalker's true nemesis

47 ___-flight checklist

48 Captured as a photo

49 An astronaut's body may retain this element during a long-duration spaceflight

Down

1 Not Lightyear but ______

2 Celestial path

3 Last name of the Blue Origin employee who flew in the spacecraft he helped develop

4 What Shepard and Glenn have in common

5 Ti-6Al-4V ___, an alloy you might need for your aircraft

6 First word of the only place the X-66 might ever fly

7 Starship's fuel tanks after reaching orbit

8 Prefix meaning "one-billionth"

11 Cube, small, LEO, GEO — these come in all shapes, sizes and orbits

14 Earth and a pizza have this in common

15 ___ and High Operations

16 Arriving shortly

18 Nautical or statute

20 How the JPL motto begins

21 Previously oversaw the U.S. supply of ICBMs

23 NASA wants to deorbit it by 2031

24 Home of the AIAA technical papers

25 What Webb and Spitzer have in common

26 Pronoun for a "Hidden Figures" hero

27 It was meant to fly

29 ____ like you fly

33 This Jovian moon will get a visitor in 2030

35 Captain Kirk's "final frontier"

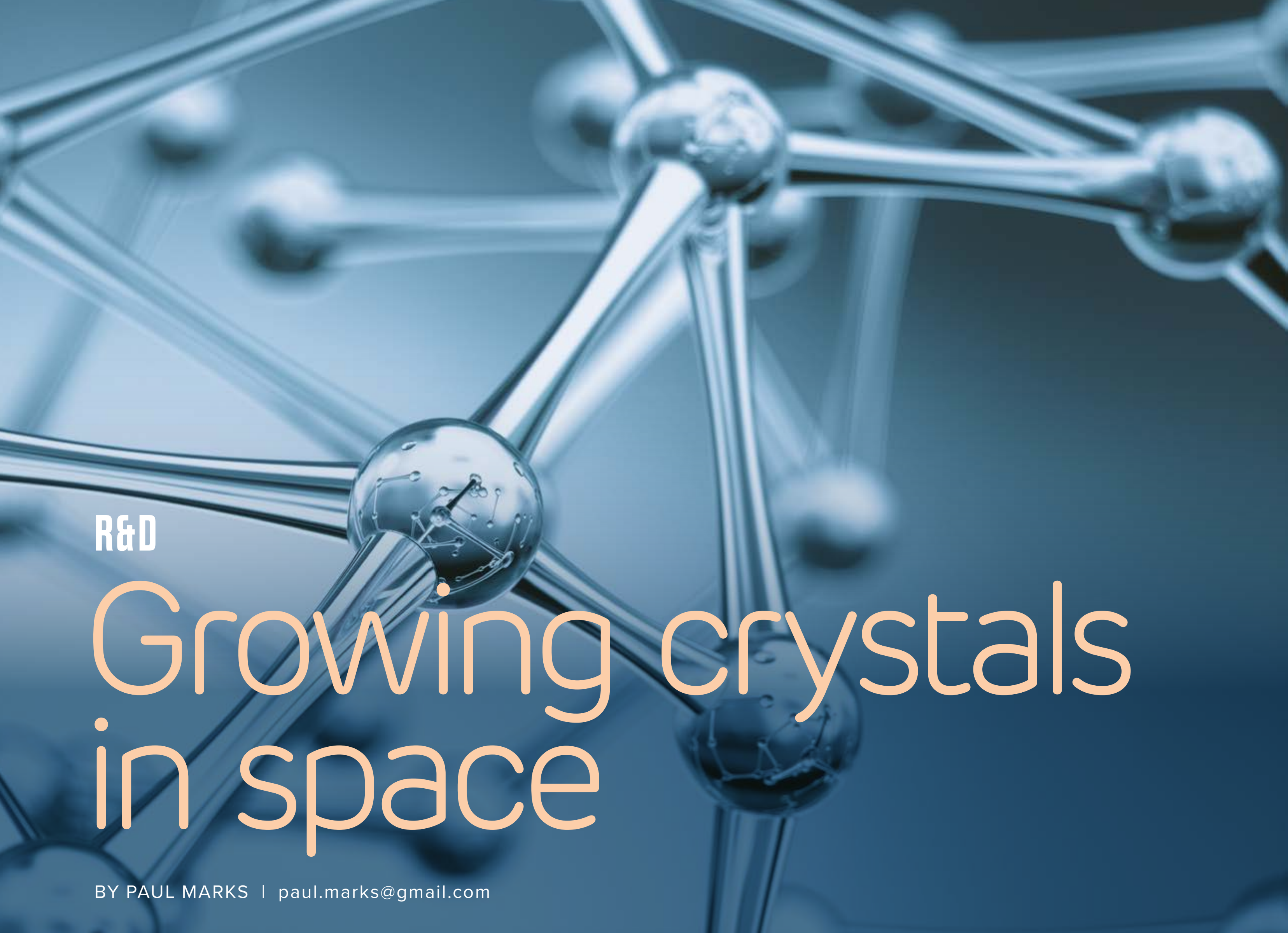
38 "Ad _____"

40 Deviate from one's course, as a ship or plane

41 When saying "satellite" would take too much time

42 Measurement of ability to maintain altitude, abbr.

43 Managed



R&D

Growing crystals in space

BY PAUL MARKS | paul.marks@gmail.com

Editor's note: *ForgeStar-1 was launched on June 23 after this issue went to print; we've updated the online version of the article to reflect the launch.*

Of all the advanced materials that could be manufactured on orbit, perhaps none are more widely anticipated than the ultra-pure semiconductor crystals that could drastically cut energy usage in a host of emerging technologies on Earth. These range from power-hungry electric cars and 5G mobile networks to the coming class of electric air taxis, plus a raft of defense and national security applications.

The company promising this orbital electronics revolution is Space Forge of the United Kingdom, a 75-person startup based in Cardiff that is preparing for its first in-space demonstration sometime this year. The goal? Grow industrially significant amounts of silicon carbide and gallium nitride semiconductor crystals in low-Earth orbit — a process first tested between the 1970s and early 1990s aboard NASA's space shuttle orbiters and the Skylab, Salyut and Mir stations.

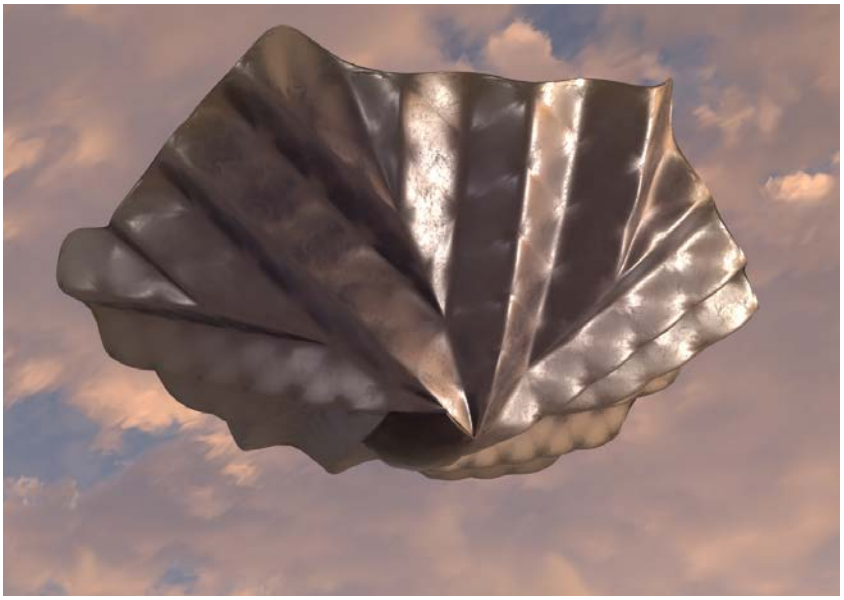
As indicated in those early experiments and ones conducted more recently aboard the International Space Station, the microgravity of LEO allows the crystals to form untethered and untouched by potential contaminants, yielding a material with far fewer defects and impurity levels than those grown terrestrially. This drastically reduces the energy these crystals will waste in the form of heat when they are incorporated into devices like power transistors for electric vehicle power trains and mobile network transmitter amplifiers.

At the center of Space Forge's envisioned operations is its ForgeStar series of reusable manufacturing satellites, each of which will house a chamber that creates the optimal conditions for growing thin, waferlike slices of crystals. These wafers must then survive the punishing journey back through the atmosphere, where they will be relocated to a lab for further growth before they are ready for manufacturing.

It's a complex enterprise, to be sure, with multiple technologies to prove. So for its inaugural ForgeStar-1 mission, Space Forge plans to attempt everything but returning the crystals to Earth.

"I think of ForgeStar-1 as like Apollo 10: a full dress rehearsal of everything up to the landing," says Andrew Bacon, co-founder and chief technology officer.

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 the new space sector.



▲▲ An illustration of Space Forge's heat shield, which is designed to unfurl like an upside-down umbrella to protect the satellite during reentry, and then double as a parachute to ensure a soft landing.

Space Forge

▲ A manufacturing model of the ForgeStar-1 satellite that's scheduled to go to orbit sometime this year.

Space Forge

For the manufacturing portion, the 30-kilogram satellite has been equipped with a smaller-scale version of the production chamber, into which gaseous feedstocks — for instance, gallium and nitrogen — will be injected. If all works as it should, the gases will coalesce into a ball of levitating matter, building on itself to create a lattice-like structure that doesn't contact the sides of the containment vessel.

And there's another benefit, says Bacon: The combination of the vacuum and microgravity kills temperature gradients and buoyancy.

"When you're trying to grow a uniform material, you don't want temperature gradients, because they cause differential growth through the material," he says. "Buoyancy makes hot gases or liquids rise in the opposite direction to gravity, which then means you end up with temperature gradients. But in microgravity, you eliminate buoyancy — so if you heat a ball [of solidifying material] to a certain temperature, it's uniform throughout the material, and you end up with fewer stress cracks."

Space Forge is not saying the quantity of crystals it's aiming to produce or how it will gauge success. But growth is not the only challenge: For the second part of the mission, ForgeStar-1 must unfold and deploy a heat shield that in future return missions will protect the spacecraft and its precious cargo during the fiery atmospheric descent.

For this, Bacon and his team are not relying on the coating of ablative tiles or material that is common for other returning spacecraft. Instead, they designed and patented a large, segmented, umbrella-like shield that unfurls upside-down ahead of the spacecraft (see picture at left). The shield is constructed from an unspecified high-temperature alloy fabric that would radiate the heat away from the spacecraft above.

"It's like opening a parachute in orbit," Bacon says. "That changes our reentry trajectory to the point where we're getting 10 times less heating. And that in turn means we can use heat-shield materials that don't burn up — or ablate — like most heat shields do."

If he's right, the ForgeStar spacecraft and their heat shields should be reusable, with the shield also doubling as the parachute that slows the satellite enough for a gentle touchdown. Space Forge had planned to test this deployment and reentry technique with its ForgeStar-0 demonstrator in early 2023, but that satellite never reached orbit due to an issue with its launch vehicle, a Virgin Orbit LauncherOne rocket.

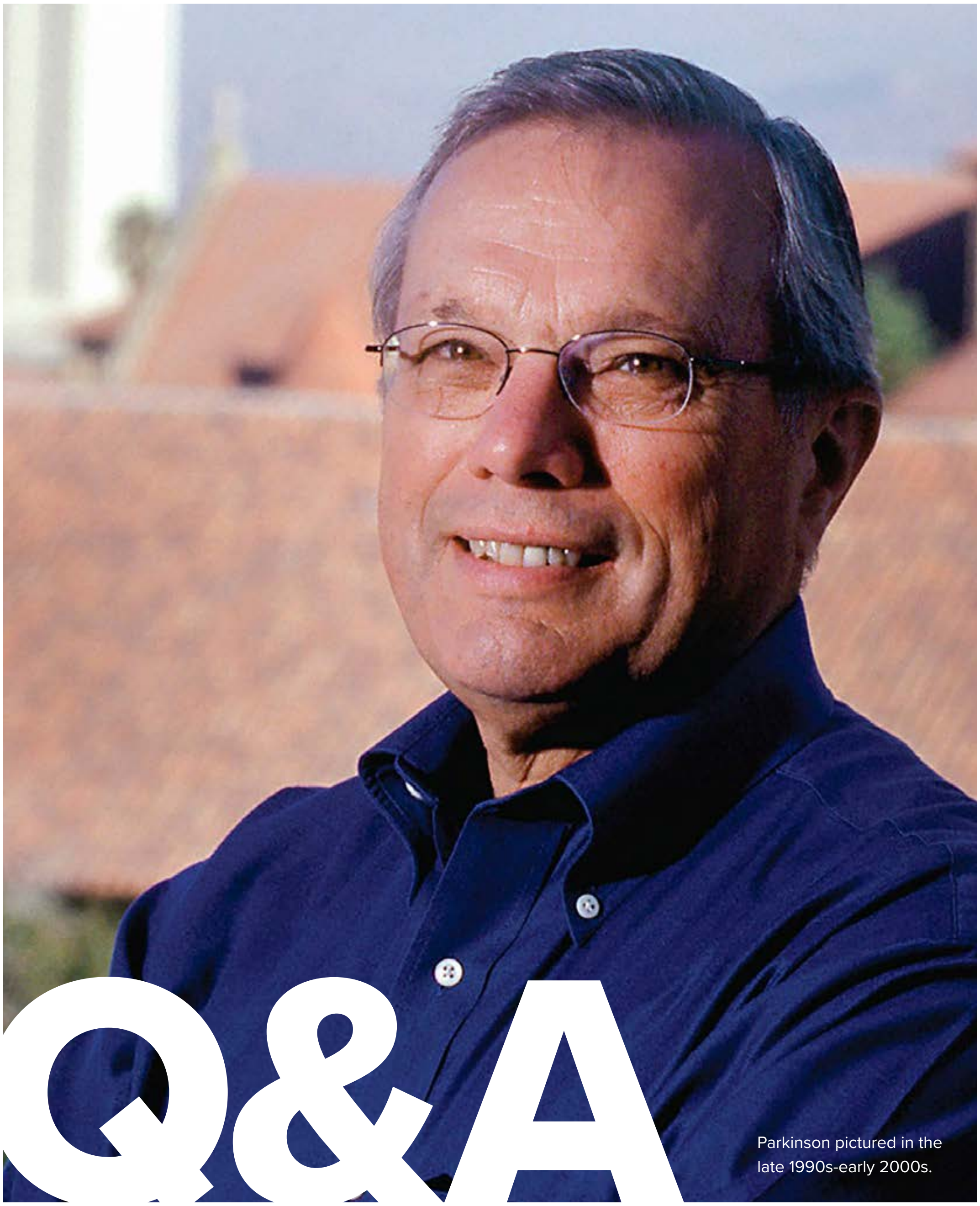
That experience, Bacon tells me, is why Space Forge is reluctant to announce a launch target for ForgeStar-1, which is slated to go up on an unnamed ride-sharing mission. "One thing we've learned from the Virgin Orbit journey is not to announce launch dates in advance because they will always slip," he says.

But if all goes well with this demonstration, a second one might not be far behind. ForgeStar-2 would test a full-size version of the crystal production chamber and attempt to return the wafers to Earth.

Once the crystals finish growing, the idea is that Space Forge will sell the semiconductor substrates to merchant market chipmakers. "Taking electric aircraft as an example, up to 20% of the mass of an electric air taxi is in the cooling system for the power train," Bacon says. "So if you can halve the energy losses with our semiconductors, you can significantly reduce the mass of the cooling system needed for the overall aircraft — and perhaps go from one passenger to two, which is a very big deal for the economics of air taxis."

There are many hurdles yet to jump, but Bacon is nothing but confident. "We did not invent this idea," he says, giving due credit to the 20th-century experimenters. "We just think that finally the time has come for this to happen."

"Every idea has its day — and today, we believe, is its day." ★



Q&A

Parkinson pictured in the late 1990s-early 2000s.

The father of GPS

Of all the space-related inventions we rely on in our daily lives, the most transformative might be the constellation of 31 Global Positioning System satellites orbiting some 20,000 kilometers above Earth. That's in no small part due to Bradford Parkinson, the Air Force officer who in 1973 led the creation of the original GPS architecture, a consolidation of the various satellite navigation projects in the works by the U.S. military. But to hear Parkinson tell it, there was some luck was involved because of the various "forks in the road" that could have led his career elsewhere. And of course, like all multibillion-dollar efforts, GPS was the product of years of work by thousands of individuals. I reached Parkinson by phone at his California home to hear about his path to the career-defining project, the lessons for future position, navigation and timing systems, and some of the exciting future applications that GPS could make possible. — *Jonathan Coopersmith*

BRADFORD PARKINSON

KEY POSITIONS:
• Since 1984 — professor of aeronautics and astronautics at Stanford University.
• 1994-1998 — co-principal investigator and later program manager of the Gravity-B, the NASA-funded satellite that in 2011 confirmed two aspects of Einstein's theory of relativity.
• 1973-1978 — director of the Global Positioning System Joint Services Program Office that developed the NAVSTAR Global Positioning System, today known as GPS.
• 1957-1978 — U.S. Air Force officer, retiring with the rank of colonel.
• 1969-1971 — professor and later deputy head of the Department of Astronautics and Computer Science at the Air Force Academy in Colorado.
• 1966-1968 — academic instructor and chief of the Simulation Division at the Air Force Test Pilot School in California.

NOTABLE:
• **Recipient** of multiple awards for GPS development, including the Queen Elizabeth Award for Engineering (shared with three colleagues), National Academy of Engineering Charles Stark Draper Prize and AIAA Goddard Astronautics Award. Also received a Bronze Star medal from the U.S. Air Force for his combat missions in Vietnam aboard the AC-130.
• **Namesake** of asteroid 10041 Parkinson, discovered in 1985.
• **Became** an AIAA member in 1967; named fellow in 1990 and honorary fellow in 2017.

AGE: 90

RESIDES: San Luis Obispo, California

EDUCATION: Bachelor of Science in engineering from the U.S. Naval Academy, 1957; Master of Science in aerospace and astronautics, MIT, 1961; Ph.D. from Stanford University, 1966; Graduate, Air Force Command and Staff College, 1969; Graduate, Naval War College, 1972.

Q: How did you become interested in engineering?

A: If you look back, there are a lot of forks in the road. One was a teacher strike in Minneapolis. My dad pulled me out of the public high school and put me in an all-boys school that taught algebra to eighth graders. I thought I'd gone to heaven. I guess I was always destined to be an engineer. I got an RCA vacuum tube manual in high school, and building electronics stuff and controls became natural for me. I went to the Naval Academy in June 1953 and graduated with the class of '57. Afterward, I chose to go into the Air Force because they had an advanced degree program, and they actually used the education. The Navy would maybe give you one tour using that education, then send you out to sea. After two years, the Air Force sent me to MIT.

Q: That was good timing, because you got a sense of what would be beneficial for the service and your career.

A: That's true. I very much was at the beginning of the Space Age. MIT had transformed the name of the aeronautics department to "Aeronautics and Astronautics." I had a whole series of courses on inertial navigation, how gyros and accelerometers work, how the system is put together, what the error equations are, the things you should look for. And fortunately, my next Air Force assignment was testing inertial navigation systems — so you could say it was kind of in my kit bag. My MIT associations were very valuable. Years later, when I was running GPS, Charles Stark Draper — someone I regarded as a semi-mentor — came to Los Angeles. My boss had me talk about GPS. Draper didn't like anything with radio navigation. He said, "You don't realize that in time we'll have a whole inertial navigation system in this," and pointed to his watch. He was before his time, but his vision was right.

The trouble is inertial navigation systems inherently are open-loop drifting things. As soon as you have any kind of bias or misalignment — which you always have, even if minuscule — it'll drift off unbounded. So an inertial and a GPS are a natural and wonderful marriage, and the good GPS sets do that.

"The people who use PNT are not all created equal — they have different needs; they have different sensitivity if it doesn't work."

Q: What happened after your Ph.D. at Stanford?

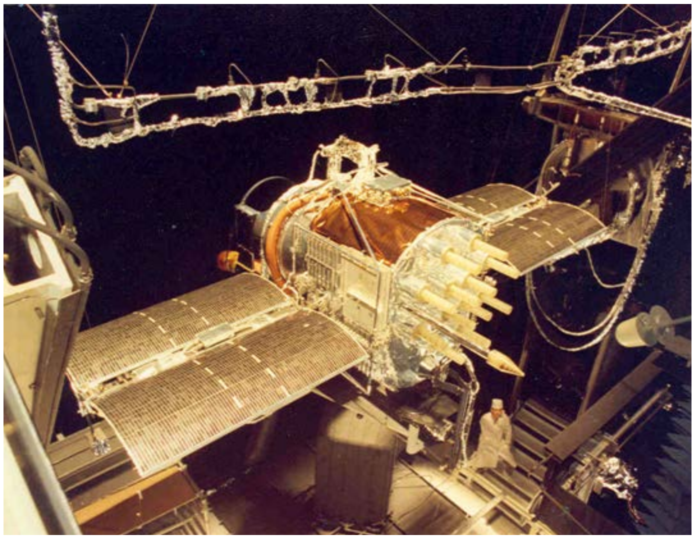
A: Another fork. I was to be a professor at the Air Force Academy. Last minute, two guys show up from Edwards [Air Force Base in California]. The lieutenant colonel says, "We want you to be on the staff, teach academics, run the Simulation Division and go flying with the test pilots. Would you like that?" Would I ever. That was the pinnacle of the flying Air Force, and these guys were fearless. They let me actually do the flying, outfitted in a full pressure suit. We flew an F-104 up to over 90,000 feet. The adventures!

Q: After that, you taught at the Air Command and Staff College and the Air Force Academy.

A: I got assigned to the Department of Astronautics and Computer Science, teaching space mechanics. One day, into my office bursts academy classmate Rick Wills. The Air Force had been trying to put together a new version of the AC-130 gunship, including a digital fire control system that points the airplane so that its fixed-side firing gun hits the target. Digital gave a lot of flexibility, but also the flexibility to be wrong. Evidently, it was wrong most of the time. Rick said, "You're the right guy to help fix this." Next thing I know, I'm heading for Wright-Patterson [Air Force Base in Ohio]. The key was either we get this fixed in time for the dry season in Laos, or rip everything out and put it back to the analog configuration.

The first AC-130 arrived in South Vietnam in 1967 for U.S. combat operations in Vietnam and Laos as part of the Vietnam War. — JC

We went down to Eglin [Air Force Base in Florida], and the test was in the Gulf of Mexico. The airplane shot the hell out of the raft, and the general says, "You're good



▲ This full-scale GPS satellite was photographed in 1977 in a testing chamber at the U.S. Air Force's Arnold Engineering Development Complex in Tennessee.

U.S. Air Force

to go." After that, I thought I'd go back to the academy and teach. But there were still some bugs in the system, so next thing you know, I'm in Ubon [Air Base in Thailand] flying combat missions every night, although technically I'm a professor.

Q: After the academy, you also taught at the Naval War College. Tell me how you got back into the field, so to speak.

A: I was at the Pentagon, working for Glenn Kent, head of studies and analysis. My folder came to Kent's deputy, Bill Manlove, who asked me, "Do you like to build stuff or study stuff?" I said, "Building stuff." And he replied, "I've got an assignment you'll really like: chief engineer on the Advanced Ballistic Re-Entry System program."

Established in 1963, ABRES was a Defense Department initiative to develop and test reentry vehicles, including the Mark 12 warhead for the Minuteman III ICBMs . — JC

Again, an abrupt path taken. I arrived in LA, and the general said, "Brad, I don't know a lot about the technical part. You decide what we do." For an engineer, how could there be a better deal than that? We were testing a lot of stuff: maneuvering reentry [vehicles] and using guidance systems in ballistic missiles. Then, as one of my friends said, "A hundred days later, Parkinson disappears." Lt. Gen. Kenneth Schultz, commander of the Air Force's Space and Missile Systems Organization, pulled me into his office one day. "We've got this little satellite navigation program called 621B," he said. "I'm thinking you're the right guy on that program."

Q: That was November 1972. How did you go about getting what became GPS off the ground?

A: 621B was floundering in competition with a Navy program, Timation, and a Navy navigation system called Transit. The Naval Research Laboratory claimed they had invented GPS, but their system was two-dimensional, required every user to have an atomic clock and used a signal structure for ranging. It was passive ranging but required a different frequency for each satellite. It also was trivially jammed. The Air Force wanted to put up a demonstration of satellites in 24-hour inclined orbits over the western United States. In August 1973, I went before the Defense Systems Acquisition Review Council and briefed the program I had inherited. What happened is I failed like hell. So when I got called in to Malcolm Currie's office, the No. 3 guy in the Pentagon, I thought my career was over. But he said, "You and I know that there's better ways to do this. Take the best ideas, come in with a new proposal, and I think we'll approve it." So we spent Labor Day weekend hashing out the ideas to synthesize the new program, which became NAVSTAR/GPS. And what we chose was, based on an Air Force study, the hardest of 12 alternative techniques for navigation using satellites. We had to simultaneously passively range to four satellites. It implied you have quite a number up there to populate your constellation to ensure you had four. By December, I walked into that same meeting, and the council said, "Let's go do it." Four years later, we had satellites on orbit. Within five years, we had tested and built 12 different kinds of user equipment — emphasis on the word "we," because those young Air Force officers and the contractors we picked, and the cadre of aerospace engineers that I retained, they made it happen.

The first GPS prototype satellite was launched in 1978, the first commercial receivers were marketed in 1984, and the 24-satellite constellation was declared officially operational in 1993. — JC

We could foresee it was going to be big. The first civilian receiver to lock up was built by students at the University of Leeds in England. That demonstrates we had freely given out the specs on the system and how the signal could be received.

Q: So in hindsight, that initial rejection was a blessing in disguise?

A: The beauty of what they were forcing me to do is show residual value. Instead of simply a demonstrator, we put up a piece of the operational constellation. It was no longer, "put something up and throw it away when you do the real stuff." Instead, if everything worked out, we had the first quarter of the constellation on orbit — and if you added another 18 satellites, you had the whole constellation.

Q: What lessons does this experience offer for future private position, navigation and timing systems?

A: The people who use PNT are not all created equal — they have different needs; they have different sensitivity if it doesn't work. They have different size pockets to spend, different demands in the time to field it, and whether five, 10 years from now, they'll still be able to use it. Cell towers, lower-Earth satellites, optical cables all have a role potentially. You have to be careful about the high end. Category A is the highest end for dynamic users. For a farmer, that's an accuracy of a couple inches dynamically. Category B is also three-dimensional, but on the order of a meter. A third category is perhaps 10-20 meters, conceivably worse and not necessarily three-dimensional. Another category is static. If I can process things statically, I can get down to millimeters with GPS. That's the standard for surveyors. Against those categories, you have to measure the proposed solutions. I was chair of a review committee for FAA on eLoran.

He's referring to the proposed enhancement to the U.S. Coast Guard's Long-Range Navigation, LORAN, a ground-based radio PNT predecessor to GPS that is now dismantled. — JC

I strongly suggested that the Air Force, FAA and the government field eLoran as a backup and a deterrent to interfering with it. But eLoran is two-dimensional and probably only guaranteed to 10 or 20 meters if you apply the same rigor you do with GPS. If you're talking safety of life, three dimensions, one meter stuff, there isn't anything that could do that except for GNSS GPS or its equivalents by others.

Q: What do you see as the biggest threats to GPS reliability and integrity?

A: A great question. Physical vulnerability, yes; the Russians could, as an act of war, start shooting at GPS satellites. I don't know how expensive, effective and reliable that would be. There are ways to make very inexpensive GPS satellites — in essence, proliferate the constellation and give them a targeting problem. That's a war game answer to a war game problem. Master control segment, you could take out physically. Each satellite stores where it thinks it's going to be in the future, and we update that every 12 hours or more frequently. If you fail, that ephemeris gradually gets ungood.

The real problem: jamming and spoofing. Nobody should be spoofed — nobody. There are enough checks and balances that you should be able to tell if someone's attempting to give you a false position, but we may not have the means to ride through it. If we have an inertial, we can ride through such things for a little while. The elephant in the room is jamming, and the reason is that the GPS signal is tiny. What do you do about that? Back in 1973-74, I persuaded the avionics lab under my program to sponsor Collins Radio to demonstrate the ultimate jam-resistant receiver. If you add deep integration with inertials, null steering antennas and perhaps a more sophisticated signal itself, you can fly right near a 1-kilowatt jammer and never see it. The U.S. government has a regulation that forbids building antennas with more than three elements. In addition, they cannot be sold, installed or used in the U.S. Only this January has the government drafted language for the International Traffic and Arms Regulations that would abandon this stupid restriction.

He's referring to the State Department's January notice in the Federal Register that it plans to update the U.S. Munitions List to end restrictions on controlled reception pattern antennas, or CRPAs, for PNT. — JC.

It's inexcusable that we don't have this solution in place for civil users.

Q: Could we have predicted what GPS has become?

A: Of course not, but we could foresee quite a bit, long before we could do those things — before Reagan had guaranteed it, before Clinton turned off deliberate disturbances. And sure as hell before very large-scale integrated circuits drove the cost down. To give the credit where it's really due, the engineers have taken ideas that in retrospect look pretty obvious and actually put them into systems that work. It's the execution that really counts. A lot of engineers deserve credit for making those visions reality. By 1984, the cost of the receiver had gone down and the real-time kinematic was shown to be robust. That opened a whole new panoply of opportunities, taken advantage of by people who probably in 1978 had never heard of GPS.

Q: What do you see as the most unexpected application?

A: Back in '78, I knew we could navigate airplanes. I didn't think we could blind land them. But in '92, we did 110 straight blind landings with a 737 loaned by United, sponsored by the FAA.

Q: Does that pave the way for autonomous cargo planes?

A: It's totally feasible. We do it all the time today but on a very small scale: UAVs, unmanned aerial vehicles, now deliver things. It's going to happen sooner or later. The bureaucracy has to screw up their courage and go down all the corner cases. Let's start moving in that direction and see what happens.

Q: Switching gears, what guidance would you give on technical leadership, based on your experience?

A: Some program managers had a tendency to sweep problems under the rug. I was the opposite. I don't want my boss surprised. If you're running a program, you got to make decisions and get on with it. Kicking the can down [the road] doesn't do much good if you have the right problem, if you don't do anything about it. One of my friends calls it admiring problems. Sit around and admire that problem. Boy, that's a great problem.

Q: You've been an AIAA member since the '60s. What's been the value for you?

A: The No. 1 value is the interfacing, the networking and listening to papers. Technical knowledge gets out, but then there's the ability to interact with the people doing that. I can think of several cases in which I reached out at a meeting with a guy and said, "I'd like to collaborate with you on a paper," and we did that. It gives an opportunity to not just network, but also to collaborate and push to state of the art, push the knowledge.

The internet has done more than books. Not only do I have the ability to print, now I have the ability to stick all this on the web, do searches, rapidly get technical papers or philosophical papers on any subject, and get knowledge and thought — good, bad, right or wrong — almost instantaneously.

The scary part now is AI. I don't have a lot of experience in AI, but this morning at our Retired Active Men [group], I knew the speaker was going to talk about cars so I gave two nice poems about cars. Then I informed the membership that I had ChatGPT write those poems — understand what I'm saying? Virtually undetectable as not being from a pretty darn good poet. Where does that lead us in synthesizing new knowledge or at least amalgamating knowledge? It's going to have an impact. I hope that we put checks and balances so that what happens is generally for the benefit of everyone, not malicious, but I don't know how to flesh out that statement. ★

ENGINEERING NOTEBOOK

Test time for hydrogen fuel cells

Now that Airbus has chosen the design for its future ZEROe airliner, the next major milestone is a planned 2027 ground test of the engine components. Keith Button spoke to engineers and program executives about the work ahead and the revised target for beginning passenger flights.

BY KEITH BUTTON | buttonkeith@gmail.com

The contenders

Airbus spent five years assessing four concepts for its hydrogen airliner. Here's how they compare.

	PASSENGERS	RANGE	ENGINES	PROPULSION
Fuel cell 	100	1,850 km	6 in the original design, 4 in the revised one	Wholly fuel-cell powered; the revised concept has two liquid hydrogen tanks feeding four 2-megawatt engines, each with fuel cells and an electric motor to turn a propeller
Blended wing body 	200	3,700 km	2	Hybrid turbofans driven by hydrogen combustion and possibly electricity generated by fuel cells
Turbofan 	200	3,700 km	2	Hybrid turbofans driven by hydrogen combustion and possibly electricity generated by fuel cells
Turboprop 	100	1,850 km	2	Hybrid turboprops driven by hydrogen combustion and possibly electricity generated by fuel cells

Graphic by THOR Design Studio, reporting by Keith Button, Cat Hofacker and Paul Marks | Source: Airbus

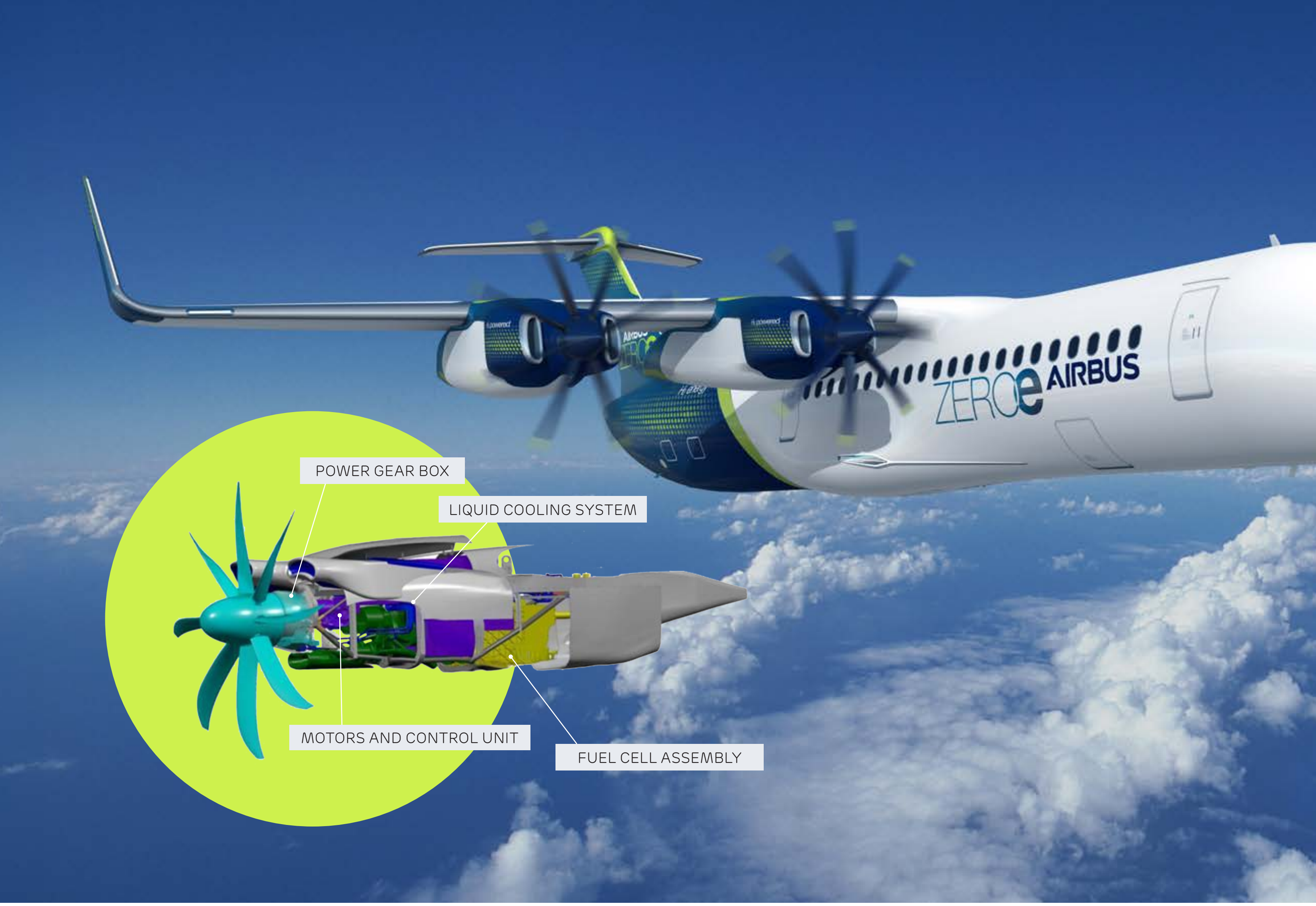
If all goes well, in two years, Gregg Llewellyn will be peering through a window from the control room in an Airbus facility just outside Munich. On the other side of the glass, attached to a metal frame the size of a small car, will be an early version of the components for a hydrogen-electric engine that the company hopes will someday propel a 100-passenger plane with a range of 1,850 kilometers and no carbon emissions.

While this setup doesn't mimic the final planned flight configuration for the engine, a successful demonstration would nevertheless mark a "major step forward," says Llewellyn, who leads the ZEROe hydrogen plane project that Airbus began in mid-2020. The company spent nearly five years assessing different airliner concepts before announcing its choice in March: a hydrogen-electric design driven by four engines. In this configuration, liquid hydrogen will be pumped from two large tanks to the engines, each of which contains fuel cells to convert the hydrogen, combined with atmospheric oxygen, into electricity. This electricity will flow to a motor control unit, which in turn will send the current to an electric motor that will drive a gearbox, which turns a propeller.

"With fuel cells, we believe we've found the right technology," Llewellyn says. The concept beat out the other three contenders [see chart above] — all of which relied on direct combustion of liquid hydrogen. That was partly because hydrogen-electric propulsion would produce no nitrogen oxide emissions and potentially no contrails, both of which are leading contributors to aviation's portion of atmospheric warming, alongside carbon dioxide. Electric power also gives aircraft designers more options for how to distribute the propellers across the airframe, he says.

Already, Airbus has revised the original concept it unveiled in 2020, reducing the number of engines from six to four based on early testing that indicated each engine

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.



would produce more power per kilogram than engineers initially predicted. Fewer engines will also reduce the overall cost of the planes, says Mathias Andriamisaina, head of testing for the ZEROe technologies.

Despite the progress, it could be another 20 years before the first passengers ride in these airliners. Airbus had been working toward entry-to-service in 2035 but dropped that target earlier this year due to what executives have described as the slow development of a global hydrogen supply network. While a new official target date has yet to be announced, Airbus predicts that the fuel market will take five to 10 years to mature, Bruno Fichefeux, head of future programs, said at a company summit in March. This would put the ZEROe aircraft's debut sometime between 2040 and 2045.

Engineers could use that extra time. Among the challenges: proving that they can transform today's bulky, heavy hydrogen-electric components suited for ground transportation and industrial uses into light, compact engines with more power per kilogram.

And so, chief among their tasks before the 2027 demo are identifying ways to boost engine power per kilo, manage fuel cell heat more efficiently and develop software that can control engine power during flight. Weight reduction goes hand in hand with these goals. Over the course of a year, engineers conducted some 1,000 ground tests over 500 hours with early engine components. The setup was similar to that planned for the 2027 demo, but with key differences. First, an industrial high-pressure tank supplied room-temperature gaseous hydrogen — not liquid hydrogen at cryogenic temperatures, as will be required for flight. Likewise, the off-the-shelf engine components were state-of-the-art for fuel-cell cars, trucks or boats, but they aren't designed with the size and weight considerations for aircraft, Andriamisaina says.

"You can use the boat or ship propulsion system," he says, "but it's so bulky that you will never take off."

Plans call for swapping out these components by the end of this year for aircraft-specific components, Llewellyn says, including upgraded fuel cells, electric motors and gearboxes. Also, the stainless steel tanks will be replaced with lighter ones that can keep the hydrogen at the required minus-253-degrees Celsius for it to remain liquid. By next year, Airbus plans to reduce the size of the test engine components by roughly half — shaving off weight by constructing fuel cells and motors out of lighter materials, Andriamisaina says.

▲ Among the challenges for Airbus engineers is how to design a lightweight, compact engine that produces enough thrust but also ventilation to allow the heat produced by the hydrogen fuel cells to escape.
Airbus

"One of the challenges is to make them all very, very compact."

Tank design will play a part here as well. Liquid hydrogen has several advantages over gaseous, starting with the lighter weight of a double-walled, vacuum-insulated tank versus the bulky tank needed to keep the gaseous fuel pressurized, typically at 350 to 700 times sea-level air pressure. So Airbus and Air Liquide Advanced Technologies of Paris are testing whether the tanks and their piping can be constructed from aluminum alloys and carbon-reinforced plastics, Llewellyn says.

While relatively new to aerospace, these double-walled tanks were adopted years ago by other industries. BMW's Hydrogen 7 sedan from the early 2000s and Norled's hydrogen-powered MF Hydra ferry that Norway debuted in 2023 rely on the technology, as do household thermos bottles. "It's not a fundamentally new technology, but it's certainly new for aerospace and commercial aviation applications," Llewellyn says.

Other benefits of liquid hydrogen are that it packs more energy per liter than pressurized hydrogen gas, and it can boost overall engine performance by doubling as coolant for its electronics. For instance, keeping the engine circuits at near-cryogenic temperatures reduces electrical resistance, Llewellyn says, which allows for "nearly unimpaired" power transmission. The company's Airbus UpNext subsidiary is designing a cooling loop that would circulate hydrogen-chilled helium to the engine's cables, motors and electronics to induce superconducting properties.

That's not to say that a fuel cell engine doesn't come with challenges, Andriamisaina says. There's heat management, for one. "When we are using conventional jet engines, the heat is just ejected to the outside," he says. In contrast, fuel cell engines require temperature management via powerful heat exchangers. Typically, metal tubing circulates a liquid coolant between the warm fuel cells. The warm coolant flows through a heat exchanger cooled by ambient air and recirculates.

This function will be especially important for the ZEROe aircraft, Andriamisaina says, because for every megawatt of power generated by the fuel cells, they will also produce 0.4-0.6 megawatts of heat. Engineers believe they will need a combined 8 megawatts of engine power for the 100-plus-passenger plane — that's 2 megawatts per engine, with up to an additional 1.2 megawatts of heat.

Off-the-shelf exchanger components won't be up to the task, so they've been bench-testing prototypes of alternative heat exchangers in France, Germany and Spain. Among the options: a single large cooling loop versus several small loops and oil versus glycol-based coolants. In general, the smaller the heat exchanger and the less cooling liquid it needs, the greater the improvement in engine power per kilo.

Also to be determined is the shape of the air intake channel on the engine' exterior, which must direct outside air through the heat exchanger to an air compressor feeding the fuel cells without imparting significant drag on the aircraft. For wind tunnel tests in Spain, engineers constructed channels out of wood, resin and metal and attached them to the top, bottom or sides of scaled-down engine models. The models were then placed in the wind tunnels, where high-speed cameras recorded the air flow around and through the engines, as traced by strands of smoke or wire, Andriamisaina says. Tests were conducted at various temperatures, wind speeds and angles of flow to simulate takeoff, landing and cruise phases of flight. Once fed into computer models, the test results showed engineers in detail where the shapes disrupted air flow.

And then there is software, which will be essential for controlling the propulsion power of the engine, Llewellyn says. The fuel cells will produce electric current by combining oxygen from the ambient air — pulled in by the air compressor — with liquid hydrogen from the on-board tanks that has been vaporized to gas. A motor control unit changes the continuous electrical current produced by the fuel cells into alternating current that can be controlled, which then turns the motor, which powers the gearbox, which powers the propellers.

The control software must be able to manage failures of any of those individual components, Llewellyn says. "You want to be able to continue safe flight and landing in the event of any of those kind of failures."

In such a scenario, the software may need to shut down adjacent components or redirect power from redundant fuel cells or electrical units in the same engine. So engineers are conducting ground tests that simulate the failure of individual components, as well as simultaneous failures of multiple components, to see how the software responds. Several versions of the software have also been tested for controlling engine power and fuel efficiency via the supplies of hydrogen and oxygen to the fuel cells and via the electrical power through the motor control units, Llewellyn says.

For throttling, for example, regulators at FAA and the European Union Aviation Safety Agency, or EASA, require that engines be able to go from idle to full thrust in eight seconds once commanded by a pilot.

"What we have to do with a fuel cell engine is show that we can achieve the same sort of requirements as what a gas turbine engine can achieve," he says.

For the 2027 demonstration, the engine will be more tightly packaged than the current ground testing setup, but not yet small enough to fit in an engine fairing, Andriamisaina says. A dynamo will stand in for the propeller, so the engine can operate under simulated propeller loads for takeoff, cruise flight and wind gusts, and the loudest noise emanating from the engine will be the whoosh of the air compressor.

Even if all goes as planned, there will still be plenty more to do before the first hydrogen airliner is ready to take to the skies.

"2027 is not the end of the story," Andriamisaina says. ★

Will advanced air mobility really change the way we travel?

THE BIG QUESTION

It's been nearly 10 years since Uber announced its Elevate initiative for "on-demand urban air transportation," in which anyone would be able to hail a small electric air taxi with the push of a button, much like ordering a car in the Uber app. In this grand vision, hundreds of battery-powered aircraft would soar through the skies, reducing road congestion and pollution and "giving people their time back." Today, this concept of advanced air mobility has expanded to also encompass scheduled service, longer-distance trips and aircraft with hybrid-electric propulsion.

That future has yet to arrive, though it may be getting closer: Chinese developer EHang in 2023 received regulatory approval for its single-seat aircraft, though passenger flights have not begun in earnest. In the U.S., California developers Archer and Joby Aviation are awaiting FAA type certificates for their four-seat designs but say they could begin passenger flights in the Middle East as soon as next year.

Will we ever travel like the Jetsons? Six experts from government, industry and academia weighed in.

— Paul Brinkmann

Victoria Coleman

CEO of Acubed, the Airbus Silicon Valley innovation unit; former chief scientist of the U.S. Air Force.

YES NO MAYBE

I think there is a great deal of promise in electric aviation technology, but it's a technology that hasn't found the right market yet. For short distances, electric aircraft are difficult to sell. People used to come to the Air Force all the time and say they can do a "short hop" flight. And the response was always, "We have Cessnas for that." Today, there isn't a single application for an eVTOL [electric vertical takeoff and landing aircraft] in any mission for the Air Force.

Part of that disconnect stems from the fact that people started with the technology and then tried to figure out what problems it could solve. But the problem and solution have to come first, and then you have to design for that. At the same time, some of that learning would never have taken place if we didn't first develop the tech. For instance, we had to design battery-only aircraft to realize that hybrid-electric propulsion might be the most promising for the near term.

In my view, the sweet spot for advanced air mobility is actually suburban or regional transport — trips like from Santa Cruz to Berkeley, which are both outlying cities in the San Francisco area. But once you get to Berkeley, it's congested, so where are you going to land? These are the problems to be solved still.

The other piece of this is to design for increased autonomy. This would relieve some of the training requirements for a pilot, and that shortens today's years-long training process. For example, I spent a lot of time flying an F-16, and they are not simple. There's buttons everywhere, and you spend a lot of time getting trained. But the first time I sat in an eVTOL, I was amazed at how simple it was. It was like the first time you saw an iPad when you were used to desktop computers. Based on that, I think a human can become competent at piloting an electric aircraft in something like three months.

Sergio Cecutta

Partner and co-founder at SMG Consulting in Arizona who maintains the AAM Reality Index, a ranking of air taxi developers based on their progress toward certification and mass-scale production.

YES NO MAYBE

I've never been one of these evangelist types that believe electric air taxis will change everything. We said from the very beginning, this is just one new tool in the transportation portfolio of a large city.

In the short term, every service, every product, when it comes out, it's always more expensive than it could be. The final democratization of this transportation technology comes when you have very high frequencies, many flights, coupled with autonomy so that you don't need a pilot on board. In the early days, when we have a few of these airplanes flying around and they all have pilots on board, it's going to be more of a premium service. After that, you can make electric air taxis super cheap by subsidizing them with public money and investors.

If you remember back to the early days of Uber, the prices were probably half of what they are now because the company was trying to grow and conquer territory, funded by investors. Today, however, you're now basically paying what it costs to take that Uber ride. So the whole idea that a flight on an electric aircraft will cost as much as driving a car is merely promotional. Let's leave that in the early brochures of Uber Elevate. But I can see such flights becoming cheaper and more affordable, eventually comparable to an Uber Black premium ride. But there is a lot of work that needs to be done to get there, and you will need a high volume of passenger traffic.

Many new entrants, new companies, thought they could fix all of the inefficiencies in today's ground transportation by bringing in the Silicon Valley mentality to innovate rapidly. They failed to understand that these are not computers that fly; these are airplanes and carry with them all of the safety requirements of being an airplane. Aircraft are not like software because there's no beta version or early release. An airplane is either certified or not certified. There's no in between.

The idea that any company in the U.S. or Europe will enter service in 2025 is just impossible. I've asked them about this and their latest answer is, "We're working on it." So rather than keep throwing out dates that are not going to work, now they're saying, "Let's just put our heads down and figure this out." Even entering into service by 2026, or early 2027, is an optimistic view of when we'll start seeing air taxis in the United States. And I believe that the first air taxi will be hybrid-electric. For now, hybrid propulsion has emerged as the only way to bring some of these benefits of electrification to market without negating the range needed for regional flights and military interest.

"Aircraft are not like software because there's no beta version or early release. An airplane is either certified or not certified. There's no in between."

An Archer pilot completed a conventional takeoff and landing with this Midnight prototype in May. Archer Aviation

Jaafar El-Awady

Professor of mechanical engineering at Johns Hopkins University in Maryland, and founder and director of the university's Computational and Experimental Materials Engineering Laboratory.

YES NO MAYBE

Electric aircraft would reduce maintenance schedules and costs and enable cleaner, quieter, and more sustainable flight operations. However, aircraft price range and stringent regulatory constraints are still obstacles.

An important aspect that must be considered is the timeline for electric air taxi services to be accessible to the public, or if they will remain a service for a tiny, wealthy niche. A small electric aircraft may cost less to build and operate (at least in the short term) than a traditional turbine-powered helicopter. However, whether an electric air taxi ride will ever be affordable enough for a middle-class urban family to choose over a metro trip or a rideshare car service remains unclear.

Think back to electric cars; for two decades, they were only accessible to the richer population. While investor dollars continued to fund advancements in this technology, the prices of these vehicles stayed out of the reach of most of the population. Only when production reached relatively high levels, making the cost more accessible, and when a robust intercity charging network arose, did electric cars begin to creep into the mainstream. Even now, prices remain notably above gasoline vehicles in many markets, and questions about longevity remain. For instance, a well-maintained gasoline car can live for decades, but a well-maintained EV car will likely need a new, costly battery replacement much sooner.

Electric air vehicles face all those same dynamics and more. Yes, the price of an air taxi might be drastically lower than a turbine-powered helicopter, but you are still looking at a price tag estimated at $300,000 to $1 million. Additionally, to enable sustainable electric flight, there is a need for battery-charging infrastructure, local approvals for takeoff and landing sites, and preapproved flight corridors.

Also, today's air traffic system isn't designed for thousands of five-seat electric air taxis buzzing around urban skies. Unless regulators fundamentally rethink airspace access, such operations will be limited to a few certified crews and some privileged passengers, just like turbine-powered helicopters are today. Also, with constrained landing pads and slow recharging cycles, fleet sizes will be small, flight frequency will be low, and per-seat costs will be high.

While electric aircraft may compete with turbine-powered helicopters for short-distance flights in remote or time-critical routes — think mountain resorts, island hops, urban executive commutes — without a revolutionary business model and regulatory overhaul, air taxis might remain a premium service for the foreseeable future.

"Whether an electric air taxi ride will ever be affordable enough for a middle-class urban family to choose over a metro trip or a rideshare car service remains unclear."

BETA Technologies in early June landed this ALIA CX300 at John F. Kennedy International Airport in New York.

BETA Technologies

Parimal "PK" Kopardekar

Integration manager of NASA's Advanced Air Mobility Mission, researching how to incorporate air taxis and drones into the national airspace.

YES **NO** **MAYBE**

I still think there is a good promise of changing mobility using the advancements in electric propulsion, increasing autonomy and with many smaller aircraft. What this does is expand the way aviation will reach different communities, in a nutshell. We are starting to see some movement already with small drones operating in limited areas, and I think that's the beginning of real advanced air mobility.

We want to see advancement quickly. Everybody's impatient and gets excited about it, but it takes time to mature, integrate and to show that it is safe. Jeff Bezos said in 2013 that Amazon would begin drone deliveries in five years. It's taken longer, but I don't think that a few years here and there matter so long as we are doing it right, and doing it in a way that will be sustainable and see steady growth. From the perspective of NASA, we are also focused on not just one or two aircraft flying, but how we make sure that the whole ecosystem survives and thrives. Aircraft and airspace and infrastructure — all those pieces have to come together.

I don't have a lot of experience dealing with other countries, so I cannot speak for them. But here in the U.S., we have the right spirit, the right type of ecosystem and a regulatory environment that allows innovation to flourish. We also have one of the most complex air transportation systems. When anyone allows a new entrant in the airspace, they have to be very diligent about not impacting the overall safety of the current users, and that takes time. There is a national strategy that's evolving, led by the U.S. Department of Transportation, and Congress is very interested in this topic. And there is already the Advanced Air Mobility Coordination and Leadership Act underway, which Congress passed in 2022.

In terms of adoption, it will likely be similar to what we saw in the development of the commercial passenger aviation sector. There was a time when only people wearing nice suits were flying, right? That's no longer the case. Passenger aviation has really become something for everyone, and that's the goal: to see how advanced air mobility can get there. If we do this right, there could be a paradigm shift 50 years from now in terms of where people can live, or offices can be located, where they can be reached by advanced mobility aircraft, without having to only be confined to places where the road takes you. The real promise of AAM is more distributed, integrated living spaces.

But first, we need to see aircraft certificated and then the manufacturing capacity increase. And then we will see growth in traffic and airspace coordination and local preparedness — electric charging stations and vertiports, that kind of infrastructure. It's a matter of funding, policies, technology readiness, infrastructure and demonstrating that it's all going to be safe. We don't want to rush into something.

"Passenger aviation has really become something for everyone, and that's the goal: to see how advanced air mobility can get there."

Joby pilots flew these two S4 prototypes over Marina, California, in early May.

Joby Aviation

Austin Moeller

Director of equity research at Canaccord Genuity, a financial services company based in Vancouver, focusing on aerospace.

● YES ○ NO ○ MAYBE

Advanced air mobility should be able to provide another form of transportation to enhance the way people are able to get in and around cities relative to the existing options — cars or trains — which are subject to congestion just because of the way our infrastructure is designed. There's just no great solution to simplify existing infrastructure or to improve it much in a city like New York, where everything's very old. There's no great way to improve the rail infrastructure, for example, so the only solution is to fly over it, to go over terrain, over the water, over all the congestion.

Air taxis won't ever be quite like Uber for the skies because the current FAA rules require that each aircraft has a pilot. So you're limited by how many pilots you have for the near future, until autonomy advances. AAM will be less expensive than current businesses that shuttle people with helicopters. But it will be more expensive than a traditional Uber. The price should be somewhere between a standard Uber trip and a helicopter ride. So if that's $80 and $200, an air taxi should be priced ideally around $150.

When it comes to urban air mobility — short trips in the cities — battery technology is already good enough. Most of these routes will be a maximum of 50 miles [80 kilometers] so that they have the required FAA battery reserve of 25 minutes in flight. And I think the leading companies are ready to scale up manufacturing to produce dozens of aircraft in the coming years. I saw Joby Aviation's California facility in March, and they were building several aircraft simultaneously. I don't think ramping up the manufacturing is the most significant hangup right now.

Most optimistic predictions for getting certified have been delayed, but I never expected anyone to get an FAA type certificate at the end of 2024. But progress is being made, and Joby at least expects to start FAA Type Inspection Authorization flight testing before the end of this year. That's like a six- to nine-month process, and I expect it to be on the longer end of that. So that would be mid-2027 for a type certificate and then a manufacturing certificate soon after. And this would be the first completely new aircraft type to be certified by FAA in more than 80 years. The last major technological innovation in aviation would have been the start of the jet age in the 1960s.

We are seeing some companies aiming to begin service early in the Middle East and the United Arab Emirates, but I still think the regulators there will wait for FAA to issue a type certificate before allowing these aircraft to carry passengers other than their own employees. *[California developers Archer and Joby have said they could begin ferrying passengers in the United Arab Emirates by early 2026. — PB]* I'm also very skeptical that EHang or any other Chinese manufacturer will be able to get certified for passenger service outside of China anytime soon; EHang's aircraft is carrying passengers without a pilot onboard.

"AAM will be less expensive than current businesses that shuttle people with helicopters. But it will be more expensive than a traditional Uber."

A Vertical VX4 prototype flies over the U.K. in late May. Vertical Aerospace

Virginia Stouffer

President of Transformational Technologies consultancy and chair of AIAA's AAM Task Force that published its final report in 2023.

YES NO **MAYBE**

The January accident near Reagan National Airport outside of Washington, D.C., soured me on the promise of AAM a little. If we can't keep a helicopter and an aircraft on approach apart in a Class B airspace, how are we going to keep these aircraft apart when there are dozens or hundreds of them flying over cities?

The first hurdle in the critical path is achieving commercial certification. Urban air mobility is not going to happen in 10 years, or even 20 years, in terms of dense traffic by electric aircraft. Closing the business case will be a big challenge. Time-consuming training of electric air taxi pilots will affect the number of flights. Even with the fuel and maintenance savings from electric propulsion, the projected cost of a ride is not a lot different than a helicopter.

The first users will be tourists and the wealthy. To get to widespread "taxi" use, the relative cost needs to be cheaper; using automation, with a remote pilot or monitor, may be the only way to achieve that. But years of flawless safe unpiloted experience are needed to prove unpiloted air taxis to the public.

The U.S. lacks low-altitude flight rules, beyond corridors. There are no defined flight levels below 3,000 feet. Precise altitude estimation and sharing will be necessary. Currently, small aircraft altitude is estimated with destination or origin pressure altitude, GPS, radar altitude or cellphones. Whatever technology we choose to use, reportable altitude needs to be at a better standard level of accuracy. Noncooperative detect-and-avoid sensing is necessary but not sufficient to enable safe density in low altitudes. Industry experts are working to write and promulgate standards in all these areas, working with FAA for approval and implementation.

We are seeing leading U.S. companies announce they will begin operations in the Middle East, which indicates a failure in the U.S. to support introduction of new vehicles. *[She's referring to plans by Archer and Joby to begin passenger service in the United Arab Emirates before the U.S. — PB]* China is very supportive of AAM business, but the U.S. is much less so. That attitudinal difference is costing U.S. manufacturers as they go to market, so it's taking much longer.

Meanwhile, China has surged ahead. The EHang 216 unpiloted aircraft achieved a type certificate from the Civil Aviation Administration of China, but is still awaiting first commercial passenger flights. EHang announced approval of essentially tourist flights, taking off and landing at the same spot, in Wuhan or Shanghai. Hopefully China's regulators value safety as much as the U.S. If not, as the Chinese AAM companies build operational hours, there will be incidents and there will be a backlash against that. From here, it is impossible to tell whether safety in China is being compromised as they move faster than the rest of the world. ★

"Whatever technology we choose to use, reportable altitude needs to be at a better standard level of accuracy."

WANTED: more eyes IN THE skies

The increasing frequency and severity of large wildfires like the ones that devastated parts of LA in January have given fresh energy to researchers and companies who believe drones should play a much larger role in firefighting. Jen Kirby looks at the state of the technology and some of the promising applications.

BY JEN KIRBY | jenkirby11@gmail.com

Picture it: All around you, a blue expanse of sky. Below, a landscape dominated by brown brush where, in the distance, tiny figures stand around a rectangle billowing smoke. The sun is shining so brightly, your reflex is to squint — except this is just a video, recorded from the belly of a drone.

This footage came from a drone flight conducted last year by Zhaodan Kong, an associate professor of mechanical and aerospace engineering at the University of California, Davis, over McLaughlin Natural Reserve. This Northern California nature reserve is about 200 kilometers south of Paradise, the site of the 2018 Camp Fire that caused some $12.4 billion in damage — the costliest wildfire in U.S. history until the Eaton and Palisades blazes in the Los Angeles area earlier this year, according to the National Fire Protection Association.

The flights were the latest in Kong's ongoing trials to determine which instruments aboard a drone could most quickly detect any nearby fires — in this case, a planned and well-monitored controlled burn. For this particular 2024 test flight, the octocopter was equipped with three modules: a camera to visually track the plumes of a burning fire; an infrared camera that could capture images even through heavy smoke; and, finally, chemical sensors to "sniff out" plumes of smoke in low-visibility conditions, like at night or when a fire is still far away. Together, the sensors would provide visuals of a fire and its GPS coordinates to help firefighters determine how best to eliminate it.

Kong's drone is just an early prototype, but it offers a glimpse into new ways that these small aircraft could be deployed to help prevent, detect, monitor and suppress wildfires, which are igniting more frequently and burning more intensely as Earth's climate continues to warm. Firefighting groups across the U.S. already use drones in a range of scenarios, from managing prescribed burns to overhead monitoring of active fires, but innovations like Kong's could make them an even more valuable tool in the firefighting arsenal.

"I think there's a very good application for them," says Bob Roper, senior policy adviser to the Western Fire Chiefs Association, of drones. "Are they the end-all to replace all the staffed aviation? No. Do they have an application in certain situations where manned equipment is? Very definitely."

Kong is designing his drone with early detection in mind, envisioning it as a kind of aerial patrol that could be stationed in the skies during times of high fire risk — say, particularly dry or windy conditions — to survey an area and provide real-time updates. If deployed in large numbers, the drones could be a way for firefighters to monitor remote areas that are difficult to reach by other means, including those out of view of fixed cameras or watch towers. They could hover above a location, tracking smoke plumes and capturing images in more detail than what's possible with geostationary satellites,

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and with GPS data attached.

The more drones that could be deployed, the better chances "you'll be able to detect the fire in a large area very quickly," Kong says.

"Very quickly" is the key. The earlier that crews know a fire has ignited, the sooner they may be able to control or extinguish it, potentially preventing massive conflagrations that burn thousands of acres, threaten property and lives, and cost tens of billions in economic damage. In other words, stop the next Eaton Fire or Palisades Fire before it can spread far enough to warrant a name.

"The shorter latency we have between the occurrence of the fire and us picking it up — it significantly diminishes the future impact," says Ankita Mohapatra, an associate professor in the electrical and computing engineering department at California State University, Fullerton, who is researching and developing early wildfire detection techniques.

While specific trends vary from region to region, a general pattern is emerging: The typical fire season is expanding due to a range of factors. A warming climate can increase droughts and dry out landscapes, which means more fuel available to burn. Fires are burning more intensely and causing more damage. From 2003 to 2023, there was a 2.2-fold increase in the number of extreme fires, according to a 2024 paper published in the journal Nature, "with the last 7 years including the 6 most extreme." The authors based their conclusions on some 20 years of observations by NASA's Aqua and Terra satellites from their sun-synchronous orbits. In this context, "extreme" refers to a variety of factors, including a fire's intensity and ecological impact, including how much smoke and carbon dioxide it emits.

Once ignited, such blazes can be extremely destructive because so many communities are in wildfire-prone areas. According to the Wildfire Risk to Communities website maintained by the U.S. Forest Service, as many as 115 million Americans live in fire-prone counties — about one-third of the entire U.S. population.

"For many places that especially make the news, it's what I refer to as the confluence of climate, people, and fuels, and they're all very connected," says Tim Brown, research professor in climatology and director of the Western Regional Climate Center at the Desert Research Institute, a nonprofit in Nevada.

The researchers, scientists, practitioners, and startups I interviewed are all in general agreement about the wildfire threat, but views differ about where drones could make the greatest contribution. Kong is among those who see an opportunity in early detection, while others are proponents of using drones to put out nascent fires or for aerial monitoring to support active firefighting operations — or some combination of all of these.

"I don't think that our solution is able to solve the entire problem," Kong says of his monitoring drone. "I think we need to attack this particular problem from multiple fronts."

Stopping 'the big one'

A round, bright green pod sits in the middle of an otherwise

▲ A Maxar satellite photographed the Palisades (left) and Eaton fires on Jan. 9. Two weeks later, CAL FIRE reported the Palisades blaze was 75% contained, and Eaton 95%.

Maxar Technologies

▲ UC Davis associate professor Zhaodan Kong has conducted some 20 flight tests with various drones to determine which combination of instruments can most quickly detect a nearby fire. This screenshot is from an October flight in McLaughlin Reserve in California, and smoke from a controlled burn is visible in the distance.

Zhaodan Kong

empty storage unit, like an alien spaceship secreted away. The black solar panels arrayed along the retractable upper shell make it look like a cross between a turtle and an enormous golf ball.

This pod is really just a hangar, the resting place for the main event: a slender, baton-shaped drone with thin black legs, wings fixed at its sides. This is Silvaguard, a prototype from Dryad Networks unveiled earlier this year. The German company is developing the drone to track and give precise coordinates for wildfires — and, eventually, extinguish small fires autonomously.

Carsten Brinkschulte, Dryad's CEO, and Pedro Silva, the company's chief technical officer, showed off the drone to reporters at their headquarters in Eberswalde, a city about an hour outside of Berlin that is known for its forests. ("Wald" means "forest" in German.) That makes it a pretty good spot to test the possible future of wildfire-fighting tech, though the Silvaguard prototype did not make a flight during my visit.

The drone builds on the company's current product, Silvanet. These solar-powered sensors with built-in artificial intelligence — each roughly the size of a smartphone — are hung from trees to quickly detect carbon monoxide and other gases emitted by a fire. Dryad trains the AI-enabled gas sensors in its lab in Eberswalde, where researchers ignite forest floor samples to hone their "electronic nose," as Dryad's Brinkschulte describes it. The lab is lined with labeled glass mason jars filled with twigs and leaves native to certain places — a Spanish forest, or a German one, for instance.

Every minute, the sensors test the air, and if they sniff something that might be a fire, do the machine equivalent of rapid breathing to confirm if something is smoldering. Each Silvanet sensor can cover about one hectare, and they are connected to one another through a mesh network — an "internet of trees." During a test I observed in the forests near Eberswalde, the first sensors detected a fire about five minutes after it was lit.

"Now that we can detect the fire within minutes, we thought, 'Hey, why don't we take the next step, and act on it?'" Brinkschulte says.

That's where the Silvaguard drone comes in. If one or more Silvanets detect a fire, a signal is sent to the hangar pod so it can open the roof. The pod does a few environmental checks — testing things like wind speed — and essentially clears the drone for takeoff, its flight plan determined by the general area identified by the sensors. If the Silvaguard, equipped with an optical and infrared camera, detects something that might be a fire, it can hover above that area and confirm, recording the size, temperature and images of the blaze.

"This is supposed to trigger another sequence, which is an extinguishing sequence," says Silva. That process of snuffing out the fire is still a work in progress, he notes, and Dryad is experimenting with different ways to accomplish this, including with water, foam and sound waves.

"We need to take it down to the whole detection and response within 10 minutes to be really effective," Brinkschulte says. "We think it can only be achieved with an autonomous drone system. I don't think that human-based response will ever get to that speed."

Other researchers share that objective of shrinking the time between detection and suppression. At the University of Bristol in England, professor Sabine Hauert and her team are studying whether they can do so with a swarm of drones. Hauert imagines that during high-risk seasons, this drone swarm could be dispatched — like a flock of birds all programmed to work together — to search for fires, using image and thermal cameras to autonomously detect any flames. If it does, the swarm could then reorganize into firefighting mode and drop an extinguishing payload onto the flames below.

"They can continue to reorganize to make sure they're still covering the space to look for other fires that might pop up," Hauert says.

They're currently testing a Windracers ULTRA drone, made by the U.K.-based Windracers, a design capable of traveling longer distances and carrying heavier payloads.

Like Dryad with its Silvaguard, Hauert envisions the swarm having a large degree of autonomy. "You imagine the fire swarm operator on the ground that sees what's happening from the swarm, sees information about the fire and has that level of control — but a lot of the decision-making and algorithms is happening on the robots themselves," she says.

Drones on the front lines

The early detection drones in development by Hauert and others illustrate possible future applications of these craft, but they're largely tailored to the very early stages of firefighting — stopping nascent and still-small fires in their tracks, rather than combating larger or rapidly spreading fires. For those later-stage tasks, drones likely won't be able to work alone.

Peter York is the California Department of Forestry and Fire Protection's battalion chief for UAS (uncrewed aerial systems) Operations. About five years ago, the department, known as CAL FIRE, began assessing how drone technology could assist in all kinds of operations, from wildland fires to water rescues. The goal was never to replace humans on the ground or assets such as piloted aircraft, he says, but to find ways to reduce the risks to them or complement their work. In his experience, drones have been most useful for providing actionable intelligence and situational mapping, such as details on the perimeter of a fire.

"UAS has been invaluable in providing real-time intelligence to our folks on the ground when there's not crewed aviation over the top that have that same capability," York says. "We're able to do it right at the back of the pickup truck with the TV over the shoulder, looking at the controller and providing — just right now, these are the exact conditions that are going on in front of you or in front of your forces."

He adds: "We're the high-end, technical lookout."

For CAL FIRE's drones, such short-range reconnaissance missions are the sweet spot, adding critical context to urgent operations, including the ones the public never hears about. York calls these the "five-acre" fires that typically don't make the news. According to CAL FIRE, 95% of California's wildfires are contained at 10 acres or less. Crews stop the fires fast, with help from piloted aircraft and other aerial equipment, and then people on the ground contain the fire.

"And that's where we're able to provide them with really good information about what they have on the ground and what maybe they can't see," York says, adding: "That's the win for us."

When it comes to extreme fires — the ones that do make the news — York and his teams use the same mapping techniques, just on a larger scale. For the Palisades Fire, for instance, York says they logged some 65 hours of flight time, with around 200 sorties. About 10 drone pilots were assigned to the Palisades Fire, and six to the Eaton Fire.

▲ U.S. Forest Service personnel prepare a drone for an aerial ignition flight, as part of efforts to combat the Oak Ridge Fire that ignited in June 2024 near Beulah, Colorado. The drone released combustible plastic spheres to start a series of controlled fires in areas inaccessible to ground crews. These would consume any available fuel, therefore limiting the spread of the larger blaze.

U.S. Forest Service

These large fires also bring additional logistics and operations challenges. When a blaze is threatening to spread unchecked, drones could add to an already overcrowded airspace that includes the larger piloted aircraft trying to douse the flames or drop retardant to stop the spread.

But with careful management and coordination, drones still have a role. Often, pilots can dispatch them to areas of a fire where crewed aircraft aren't, so they can feed information to supervisors. Other times, the drone pilots work alongside supervisors who may ask them to fly over and investigate certain areas. York says that in rare circumstances, the CAL FIRE UAS division will alternate flight times with other aircraft so drones can be sent up to get an up-to-date site picture.

Ultimately, York says, it's however the technology can best serve the ultimate goal of stopping the wildfire. "We're providing a real-time intelligence product to those folks, but we do that very strategically and systematically."

Finding their niche

For all their potential, drones have their limitations, too. Octocopters and other small, consumer designs are ideal for hovering over specific locations to deliver precise images and GPS coordinates, yet that also translates to shorter flight times. These drones often can't travel long distances or loiter for long without coming back to base. Flight times are also dependent on factors including environmental conditions, like heavy winds, all of which adds up to little margin for error in operations. One challenge Dryad Networks has encountered in testing its drone: training the Silvaguard to maneuver among trees to drop its fire-suppression payload — then get back out — without ramming into branches along the way.

Another key challenge is seamlessly integrating drones alongside piloted aircraft. “Both industries — the man and the unmanned — are still kind of like that junior high school dance where everybody’s looking at each other,” says Roper, the Western Fire Chiefs Association adviser. “They’re trying to figure out, ‘Where do we go?’”

Seasoned wildfire crews are good at what they do, and the reality is that not every new technology will make their jobs easier. Throwing too much technology at a problem might be counterproductive.

“You have to coordinate your air, your manned air resources, with what people are doing on the ground, to support those firefighters on the ground,” says Paul Petersen, executive director of the United Aerial Firefighters Association, which represents the aerial wildland fire industry. “To just put UAS up without providing a tangible benefit to the firefighters on the ground, it’s like lighting the other side of the road on fire. You’re really not helping the situation at all.”

Logistical challenges play a role here as well, because the internet connectivity that many drones require may be unreliable or even nonexistent, especially in remote areas. It can also be difficult to manage airspace in low visibility situations, something NASA is attempting to address through its ACERO project, short for Advanced Capabilities for Emergency Response Operations. In March, researchers tested their suitcase-sized portable airspace management system, designed to share and display the locations and planned flight paths of all crewed and uncrewed aircraft operating in a particular scenario. In areas with poor internet connectivity, PAMS can rely on radio communications.

In the end, what might prove the most challenging is adopting all this new technology at scale. Prototypes and field tests can help demonstrate the capabilities of drones, but if firefighters are to rely on them — especially autonomous designs — their efficacy needs to be proved before departments spend dozens of hours and thousands of dollars integrating the craft into their tried-and-true operations.

Complicating matters is that, as Petersen says, there is no large, centralized program on the federal level — think DARPA for wildfires — dedicated to studying and testing new technologies. The adoption of drones and related technology is likely to happen in fits and starts, or on an ad hoc basis.

Yet he believes drones and other innovations will increasingly become integral to fighting wildfires. “If we didn’t try new technology,” Petersen says, “we’d still be fighting fire with burlap sacks and buckets.” ★

GODDARD
CENTENNIAL SERIES

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

The origins of liquid-fueled rockets

Today, the name "Robert Goddard" is synonymous with liquid rocket propulsion — but history could have played out quite differently had the physicist and engineer pursued any or all of his other early ideas. Historians Roger D. Launius and Jonathan C. Coopersmith describe the possibilities and the scientific method that put Goddard on the path toward the March 1926 launch that redefined rocketry.

BY ROGER D. LAUNIUS AND JONATHAN C. COOPERSMITH

It wasn't much to look at, and it only lasted three seconds, but nonetheless, the flight of Robert H. Goddard's first liquid-fueled rocket on a relative's farm near Auburn, Massachusetts, was the "Kitty Hawk" event of space exploration. This pioneering work in liquid-fuel rocketry became the cornerstone of Goddard's legacy, but equally important for spaceflight was his research ruling out other proposed methods of reaching orbit.

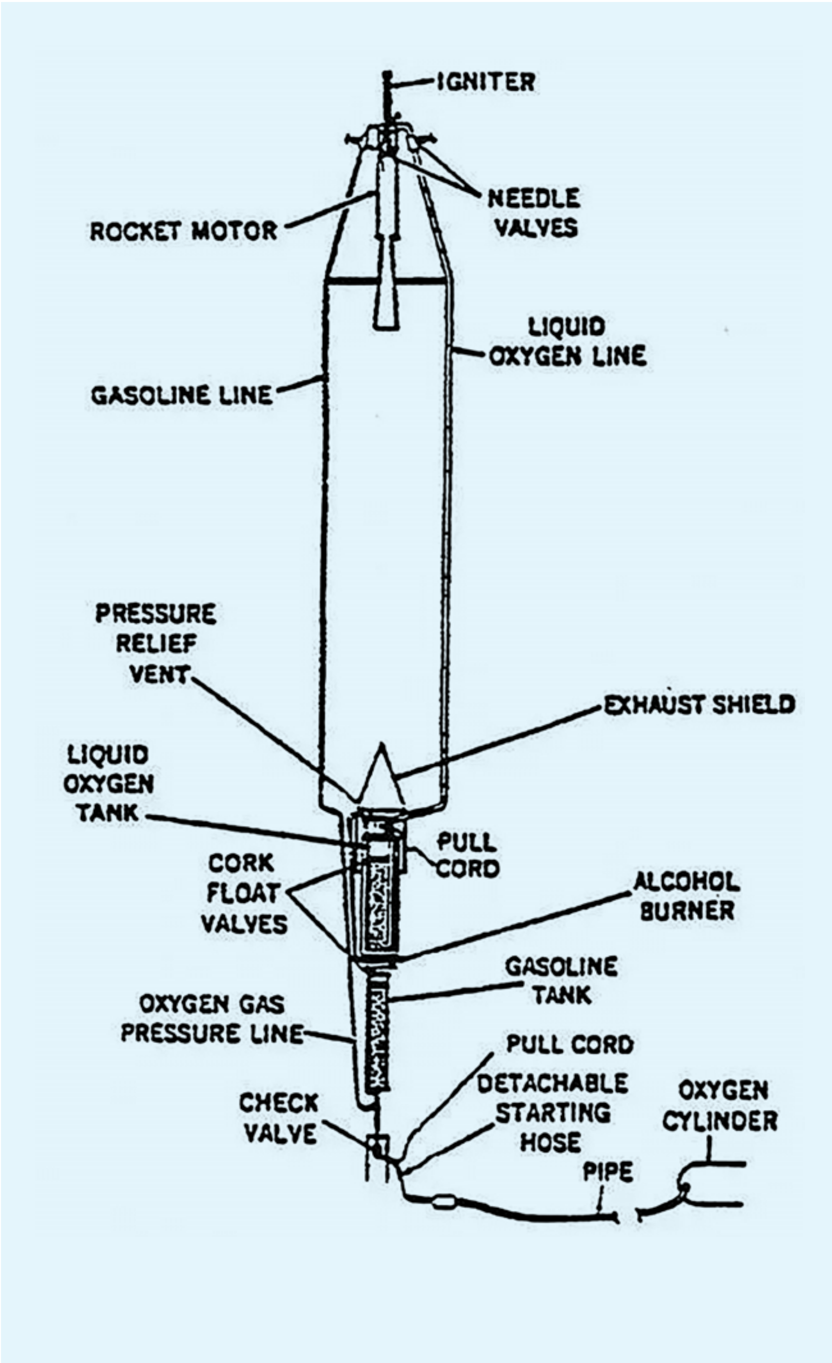
While perhaps underwhelming by today's standards, that first launch was the culmination of years of research into efficient space travel — work that Goddard was conducting at a time when few others around the world recognized its potential.

Like many in the aerospace profession, science fiction was the root of Goddard's motivation and excitement about the possibility of exploring space. After reading these stories in his childhood, at 19 he wrote his 1901 short paper, "The Navigation of Space," arguing that one could reach orbit by firing several cannons "arranged like a 'nest' of beakers." While not fully developed, this idea eventually led him to propose multistage rockets for reaching space.

When Goddard began seriously working on spaceflight as an undergraduate physics major in the latter half of the 1900s, several methods of reaching space had been proposed by various theorists and writers. While some of these had a degree of practicality, many more would still be considered unfeasible.

Consider, for example, shooting people into orbit with two oppositely polarized magnets, one of which would carry a spacecraft. Jules Verne famously shot a spacecraft to the moon in his 1865 novel, "De la Terre à la Lune" ("From the Earth to the Moon"), from a giant cannon. Another method, championed by novelist Edward Everett Hale in his 1869 The Atlantic Monthly story, involved two spinning flywheels hurling a space station into orbit: "It was not to be by any of your sudden explosions. It was to be done as all great things are done — by the gradual and silent accumulation of power. You all know that a flywheel — heavy, very heavy on the circumference, light, very light within it — was made to save up power, from the time when it was produced to the time when it was wanted."

What separated Goddard from other spaceflight enthusiasts and their theoretical imaginings was his emphasis on systematic experimentation. Early on, he calculated the energy released with solid-fuel rockets and found it insufficient to escape the Earth's gravity. He also calculated the energy required to be expended by a cannon to reach Earth orbit and concluded that the high G-forces required would smash a human passenger into mush. By 1908, Goddard had determined that magnetic, atomic, cannon, flywheel and solid fuels were, based on the state of technology, impractical if not fantastic ways to launch payloads. Consequently, only liquid fuels — and then only the less efficient but easier to handle options — provided a feasible path to orbit.



▲ A schematic of the rocket that Robert Goddard launched in March 1926. In subsequent designs, he moved the engine below the propellant tanks, as is standard for today's rockets.
U.S. Air Force

That brought him to the next question: Many believed rockets held the most promise, but what kind of rocket? While gunpowder rockets had existed for almost 1,000 years, Goddard determined that these did not generate enough thrust to reach space. Indeed, it was not until the 1960s that solid-fuel rockets reached that capability with the Minuteman ICBM.

Goddard captured his uniquely systematic approach to these and other experiments in his famous "Green Notebook." In one entry, written in July 1907 while he was an undergraduate at Worcester Polytechnic Institute, he posed three related research questions:

Problem 1. Find minimum of energy required to leave the planet, in a swarm [a concept eventually called staging].

Problem 2. Find mass to be ejected, and velocity of ejection, allowance for changing total mass.

Problem 3. Find velocity of explosion, molecules or group — on what does the temperature depend — slow burning = same temp, is instantaneous burning? What influence has suddenness intend. Know V: consider mass, em [ejected] as potential.

Solving those problems proved a challenge. By the end of 1908, he had learned through considerations of theory and copious laboratory experimentation that none of the options in vogue at the time produced the necessary energy to achieve space access. Now pursuing graduate studies at Clark College (later University) in Worcester, Massachusetts — where he later became a professor of physics — Goddard turned to the possibility of propelling a spacecraft using atomic energy, which he explored in his essay "On the Possibility of Navigating Interplanetary Space." Several publishers rejected the article, even though the editor at Scientific American called it "most ingenious" and rejected it only because of length. The essay was published later in Goddard's 1960 collected papers.

After a stint with the military in World War I, where he worked on solid rocket technology for use in combat, Goddard turned his full attention to liquid rocket propulsion. He theorized that liquid oxygen and liquid hydrogen were the best fuels in terms of specific impulse, or ISP — the measure of the number of seconds it takes a rocket engine to produce a pound of thrust from a pound of propellant — but that a combination of liquid oxygen and gasoline was less volatile and therefore more practical. To support his investigations, Goddard applied to the Smithsonian Institution in 1916 and received a $5,000 grant from its Hodgkins Fund. By providing the funding necessary to move from theoretical predictions to laboratory experimentation, this grant proved a critical milestone in rocket development.

His research was ultimately published by the Smithsonian in 1919 as the classic study "A Method of Reaching Extreme Altitudes." In it, Goddard argued from a firm theoretical base that only liquid-fueled rockets could reach the upper atmosphere and Earth orbit. More ambitiously, he calculated that with a velocity of 6.95 miles/second, without air resistance, an object could escape Earth's gravity and head into infinity or to other celestial bodies — what soon became known as the Earth's "escape velocity." The study also became the

“Goddard argued from a firm theoretical base that only liquid-fueled rockets could reach the upper atmosphere and Earth orbit.”

FACT

IN 1903, RUSSIAN SCHOOLTEACHER KONSTANTIN E. TSIOLKOVSKY published an obscure paper, “Exploration of the Universe with Reaction Machines,” that proposed the then-radical use of both liquid oxygen and liquid hydrogen as fuel. Tsiolkovsky’s work was almost entirely theoretical and virtually unknown outside of Russia until the 1920s.

great joke for those who believed spaceflight either impossible or impractical. Some ridiculed his ideas in the popular press, much to the consternation of the already reserved Goddard. Soon after the appearance of his publication, he commented that he had been “interviewed a number of times, and on each occasion have been as uncommunicative as possible.” The New York Times was especially harsh in its criticisms, referring to him as an impractical academic dreamer whose ideas had no scientific validity. The editorial also compared his theories to those advanced by the novelist Verne, indicating that such musing is “pardonable enough in [Verne] as a romancer, but it is not so easily explained when made by a savant who isn’t writing a novel of adventure.” The Times questioned both Goddard’s credentials as a scientist and the Smithsonian’s rationale for funding his research and publishing his results.

The negative press prompted Goddard to be even more secretive and reclusive. It did not, however, stop his work, which eventually led him to that Auburn farm for that fateful flight on March 16, 1926. This early liquid oxygen-gasoline rocket was oddly shaped, sporting a thrust chamber and nozzle at the top of a structure that looked more like an erector set contraption than anything resembling the rockets routinely flown today. That more common configuration we have come to associate with launchers would come just a few years later.

The flight itself must have appeared rather uneventful. The rocket flew for only 2.5 seconds, climbed 41 feet and landed 184 feet away in a cabbage patch. Regardless, it demonstrated that this was the core technology needed to reach space. Like the Wright brothers at Kitty Hawk in 1903, Goddard’s 1926 flight proved an inauspicious beginning to a spectacular future.

And to its credit, the Times admitted it was wrong about his ideas — on July 17, 1969. ★

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 an historian of technology and former professor at Texas A&M University in College Station who has written about the failures of 20th century space commercialization.

Staying alive

Designing and building life support systems for space stations requires a delicate balance of knowledge, safety and cost. As a handful of companies proceed with plans to develop their own stations to succeed the International Space Station, Jonathan O'Callaghan explores how they're approaching the challenge.

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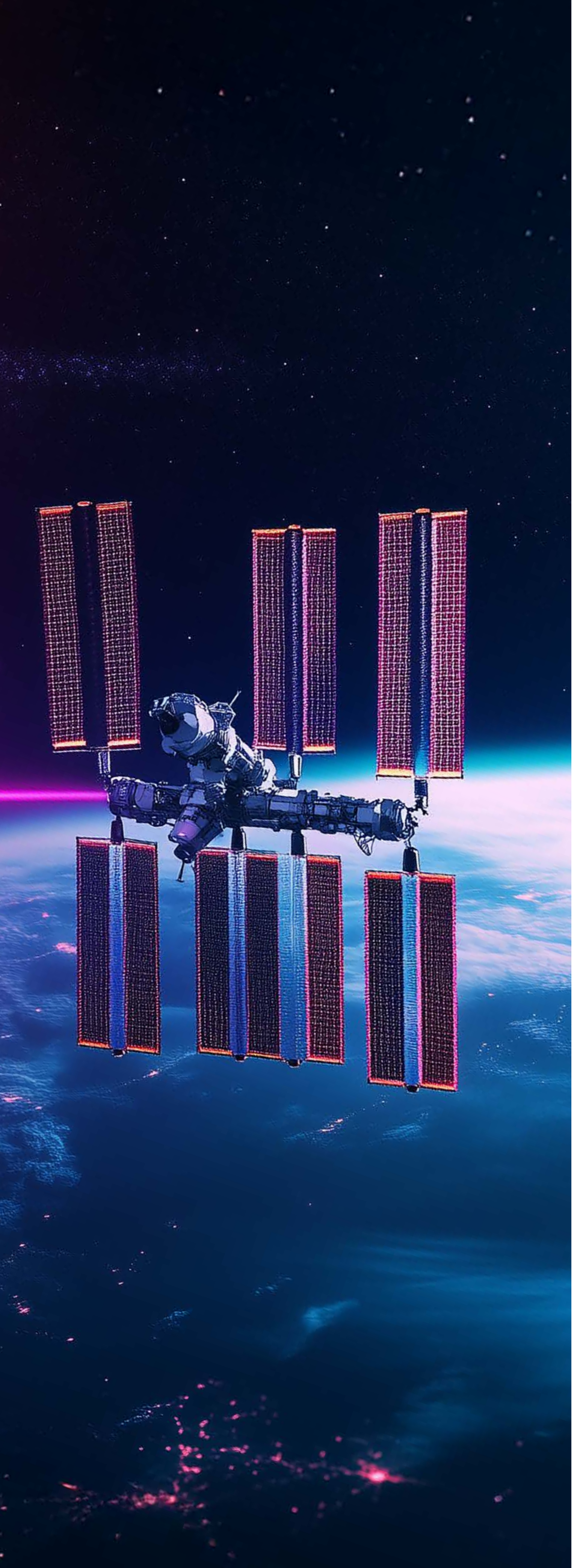


When former NASA astronaut Janet Kavandi flew to space for the first time in 1998, she encountered a peculiar problem. During the mission, one of her colleagues floated over to a corner to grab a bag but, while there, suddenly started to feel lightheaded and nauseated.

The cause, as it turned out, was the air quality in the corner: "It had too much CO2," says Kavandi. The crew member was fine once they moved away.

Kavandi, who was president of Colorado-based Sierra Space from 2021 to 2023 and now runs her own consultancy, cites the memory to me as an example of the complexities that must be addressed to keep NASA astronauts and other customers healthy and energetic aboard the coming class of privately owned and operated space stations.

Jonathan O'Callaghan is a London-based space and science journalist. A regular contributor to Scientific American and New Scientist, his work has also appeared in Forbes, The New York Times and Wired.

The challenge is real, even if no one has ever died on a space station. There has, in fact, been only one deadly incident above the Kármán line, the internationally recognized boundary of space. When three Soviet cosmonauts undocked their Soyuz 11 spacecraft from Salyut 1, the world's first space station, in 1971, they experienced a depressurization event prior to reentry and, upon landing, were found dead in their capsule. Aboard a station, one of the closest brushes with calamity occurred in 1997 on Russia's Mir. A solid-fuel oxygen generator, also known as an oxygen candle, was triggered to provide supplemental oxygen through a safe chemical reaction but instead ignited. A 3-foot flame shot out of the canister for several minutes, and it took hours to clear the station of the resulting toxic smoke.

NASA knows these stories all too well, and that partly explains why for decades the agency has kept a careful account of its successes — and challenges — with the life-support systems on the International Space Station. But now, a seismic shift is coming. NASA, through its Commercial Low-Earth Orbit Development Program, plans to hand over the responsibilities of space station design and maintenance to the commercial industry in its entirety for the first time and shift to being a major customer of the companies that establish their own stations in low-Earth orbit.

Of course, these stations will have to meet certain high-level performance standards laid down by NASA before the agency is comfortable sending its astronauts and possibly other employees. And life support has been singled out as a chief concern.

"Our biggest worry point is environmental control and life support systems," Jim Free, NASA's former associate administrator who retired in February, said during a plenary talk at the AIAA SciTech Forum in January. He elaborated in a follow-up interview, noting NASA's own struggles in developing life support technology across all its programs, not just ISS and the planned commercial stations.

"It's difficult to build those systems," he said.

So, what are the challenges involved, and how are companies coping? Let's take a look.

▲ The life support technology on the International Space Station has operated for nearly 25 years, though not entirely without incident. Former astronaut Janet Kavandi, pictured here during a 2001 flight, recalled an incident in which a buildup of carbon dioxide in a deserted corner left one of her crewmembers feeling temporarily woozy.

NASA

Setting standards

We'll start with the guidance that NASA has provided to the commercial station builders. In the 2023 CLDP-REQ-1130 document, short for "Requirement and Standards for the Commercial Low-Earth Orbit Development Program," the agency laid out broad performance metrics. For example, the level of CO2 aboard the stations should not exceed 3,950 parts per million. However, how companies choose to design or procure their life support technologies — more formally called Environmental Control and Life Support Systems, or ECLSS, pronounced "ee-cliss" — to meet these standards is up to them.

"They'll basically say, 'If you want us to put astronauts on your [space station], you need to satisfy our safety, crew and life support teams that your system will be safe for our crew to use,'" says Brent Sherwood, a former senior vice president of space systems at Blue Origin, which is developing the Orbital Reef station with Sierra Space under contract with NASA. He notes that this is similar to how the agency structures its requirements for the Artemis lunar missions, as well as astronaut transportation to and from ISS under the Commercial Crew program.

Each side has vested interests. NASA, which with its partners is making plans to deorbit ISS by early 2031, is counting on the commercial operators to pick up the station's scientific legacy and maintain the continuous U.S. presence in orbit that began in 2000. Meanwhile, the host of aspiring station operators — including the three multicompany projects that NASA has awarded a collective $400 million — are counting on the agency to be their anchor tenant.

ECLSS refers to "basically all the things that you need to keep us squishy humans alive," says Andrew Tidwell, a principal systems engineer at Northrop Grumman in Virginia who is also a lead engineer on the ECLSS for NASA's planned Lunar Gateway station that the Trump administration has proposed canceling. The list includes devices to generate oxygen from water through electrolysis, recycle oxygen from exhaled CO2, turn urine into potable water and, of course, toilets and methods of storing food in compressed form.

There is some flexibility in how the commercial stations approach NASA's standards, with the agency requiring "development and performance milestones to review and/or approve the selected provider's progress toward system certification," a NASA spokesperson told me in response to emailed questions. The agency did not make anyone from the Commercial Low-Earth Orbit Development, or CLD, Program available for interview.

The spokesperson said the process "will culminate in a certification review to provide evidence that the commercial space station, including the ECLSS, has met all NASA requirements and provide documentation of crew safety and mission assurance risks associated with the space station."

Certification efforts are underway now, with some

The future station operators and where they stand

A handful of companies are vying to take over the role of microgravity research platform after ISS is deorbited. New services are also envisioned, including manufacturing and orbital tourism.

Station	Operator(s)	Initial configuration	Planned orbit	Maximum crew size	Targeted operational date	Funding
Axiom Station	**Axiom Space** *Houston*	Five rigid modules, the first of which would to be launched in 2027 to dock with ISS. That module would separate in 2028 and be joined by a habitat module, with three others following.	400 km after detaching from ISS	8	2028 (two modules)	$140 million NASA contract to attach at least one module to ISS; $480 million in private investment as of August 2023
Haven-1	**Vast** *California*	One habitation module, to be launched inside the payload fairing of a SpaceX Falcon 9. Haven-1 is to be a precursor to larger stations that would be launched by Starships.	425 km	4	2026	Undisclosed amount from founder, billionaire Jed McCaleb
Orbital Reef	**Blue Origin and Sierra Space** *Washington/Colorado*	Three rigid modules provided by Blue Origin, and one of Sierra Space's inflatable LIFE modules.	400 km	10	2030	$172 million NASA contract and an undisclosed amount of private investment
Starlab	**Starlab Space** *Joint venture of Airbus and Voyager Space of Colorado*	One rigid module, built by Airbus, to be launched by a SpaceX Starship.	400 km	4	2028	$217.5 million NASA contract, $15 million from the Texas Space Commission and an undisclosed amount of private investment

companies contracted under CLD already passing key milestones. Among them, Blue Origin and Sierra Space demonstrated they could recycle water from urine and identify contaminants in water. As of late 2024, plans called for beginning assembly of the Orbital Reef station in 2027 toward the eventual goal of sustaining a crew of 10.

"NASA provides us with a series of performance requirements," says Shawn Buckley, Sierra's vice president of destinations and in-space infrastructure. "We bring all that together and then create our master documents of our requirements."

Station developers expect this performance-based approach will give them a freer hand during the design process. "Will we adopt all these standards, or relax some of them?" says Barry Finger, a principal systems engineer at Starlab Space. The Colorado company is a collaboration of multiple entities, including Airbus and Voyager Space, created to oversee the development of the Starlab station. Launch is targeted for sometime in 2028 aboard a SpaceX Starship, after which Starlab could host up to four crew members at a time.

"There might be a few areas where we try to push the envelope a little bit," Finger adds. "But the truth is, to keep a human alive, it is a relatively small range of temperature, pressure, oxygen and CO2 levels. I don't think we'll deviate a lot from what NASA has already established on how the ISS operates day in and day out."

Safety first

Of the many, many factors to consider when developing a life support system, one of the most important is potable water.

"NASA has a specification for what they'll allow their astronauts to drink," Finger says, including limits on "inorganic and organic contaminants."

Even something as simple as using a piece of equipment comes with guidelines, such as the curvature of the object. "You don't want a sharp corner," says Finger, lest an astronaut or visitor get injured while moving around.

There are also more unusual standards, like the color of labels and indicator lights. "You don't want to be showing the color red on an indicator light unless it really means something bad," says Finger. But of the many challenges, perhaps none rank above toilets.

"It's sort of legendary that toilets are challenging in microgravity," says Sherwood.

Here, the stakes are about safety, not just the convenience of the crew. "The system has to work reliably for different body types while using minimal water," says Anastasia Prosina, a California consultant for commercial space habitat development. "Even a small malfunction can become a major hazard. If a blockage occurs, it could lead to backup and potential leakage of waste material into the cabin environment."

The maintenance and care of life support technology is also a challenge, says Finger, with multiple moving parts involved. As an example, he references how a certain historic spacecraft — which he declines to name — encountered an unforeseen issue with a water pump, despite the system being otherwise perfectly designed. "There was a gas bubble, and it lodged itself right where the impeller [a rotating blade] is," he says. "And the blade just spun. It wouldn't move anything. It wasn't designed to pump air."

Then there are other challenges that seem menial but are equally important to astronaut safety.

"There is bacteria, condensation buildup, the cleaning of everything," says Buckley of Sierra Space. "How do you wipe down all of your systems? How much Velcro do you put on the space station, and where do you put it? And how do you pull the Velcro off so you don't create a static discharge in a highly oxygenated environment? There are so many things that come into a life support system."

The commercial station builders must also consider the costs of technology development to an extent that NASA hasn't. "If we're looking at private industry, they are trying to make a profit," says Tidwell, the Northrop Grumman engineer. That might encourage companies to develop more of their components in-house to "own the cost," he says, rather than buying off-the-shelf products.

"There are only so many companies that can survive making space-rated smoke detectors, for example," he notes. "So you end up in this balance of where can we innovate on technologies to save us money, and where does it make sense to buy things commercial off the shelf. It's a hard balance to find."

Even then, finding the right off-the-shelf products can be difficult and require companies to get creative. "It's not a big industry," says former astronaut Kavandi. "Very few companies develop only for space-based environmental systems. So if there are filtration systems that airlines use, for example, they can take good ideas and apply them to space operations."

New ideas

While humans have safely lived and worked in LEO continuously for 25 years, the coming class of stations provides an opportunity for fresh thinking.

"There is definitely room for innovation," says Finger. "But you want to build on what's been done in the past."

For example, one alluring goal of spaceflight is to develop entirely closed-loop systems, meaning everything on a station would be recycled and reused. In this model, plants and other food would be grown aboard, allowing a station to exist without the continuous resupply flights that ISS requires.

"Currently on the ISS, you could claim it to be closed to maybe 80 to 90%," says Max Haot, the CEO of Vast in California, which plans to launch a small station called Haven-1 to LEO next year. ISS reuses many commodities, including urine on the U.S. side for drinking water, "and it took a huge amount of effort to get to that efficiency," he says — but it still doesn't amount to a true closed-loop system.

▲ NASA in 2021 launched an experimental version of this carbon dioxide scrubber to the International Space Station. The design was meant to be an upgrade from the original unit that has operated since 2001.

NASA/Fred Deaton

Vast, which does not yet have NASA funding, also plans for Haven-1 to be open-loop, with many functions to be provided by the SpaceX Dragon capsule that will bring up the crew and dock with the station. To circulate air in the station — and prevent buildup of CO2 like the one encountered by Kavandi's crew member — there is to be a ventilation duct between Dragon and Haven-1.

"Vast has been collaborating closely with SpaceX on the design, analysis, and testing of this duct to ensure the air will be properly exchanged," Vast told me by email.

Dragon would also remove CO2 from Haven-1 and serve as the station's humidity system and toilet. That will limit Haven-1 missions to "40 days of crew time for four people," says Haot. For the company's second station, the multimodule Haven-2, Vast plans to bring up more consumables to allow for stays of up to 720 days with each module.

Developing technologies to close more loops than is possible on ISS could be beneficial for more than just these commercial stations. The tech could be adapted or even used as is for eventual crewed missions to the moon or Mars, says Angelo Vermeulen, a space biologist and complex systems engineer at Delft University of Technology in the Netherlands.

FACT

NASA IS TARGETING 2026 for the next round of funding under the Commercial LEO Development Program.

"You can throw a lot of money at a very wasteful mission where people are living on Mars and every single molecule they need to eat is being shipped from Earth, but that's just not sustainable," says Vermeulen, who worked on the European Space Agency's Micro-Ecological Life Support System Alternative project. "It'd be much better to use the resources that you have at hand."

Manageable risk

Other improvements are possible: The station builders might also take a look at efficiencies in a way NASA hasn't done before, says Buckley of Sierra Space. "Do you need all of the systems" that are on ISS today, "or can you reduce down the number of systems?"

Sierra plans to test some of the life support for Orbital Reef during uncrewed flights of its Dream Chaser spaceplanes, the first of which is scheduled to be launched to ISS later this year. The spaceplane's life support systems are comparable to what will be used for Orbital Reef, says Buckley, including maintaining an atmosphere inside the spacecraft "that allows us to dock to the ISS."

For the sake of reducing costs, operators might also consider lower risk thresholds than NASA has previously tolerated, says Mislav Tolusic, the chief investment officer and co-managing partner at Marlinspike, a venture capital fund based in Washington, D.C.

"There's a huge risk aversion" in spaceflight, says Tolusic, adding that many of NASA's standards have an extremely high bar. "I think we should revisit them," he says. "Absolutely, we should."

He points to a 2021 spacewalk that NASA postponed based on modeling that indicated the risk of the astronauts getting struck by space debris had increased by 7%. Tolusic says despite the seemingly high percentage, the overall risk remained incredibly low.

"The baseline risk of noncatastrophic penetration of a spacesuit is one in 2,700," says Tolusic. "The probability of dying in a car crash over a lifetime is under 1 in 100. So that made zero sense to me."

Despite the potential benefits, don't expect commercial space station operators to rock the boat too much at first, considering the high stakes involved.

"Life support for humans is just so critical, so you want to build on what's been done in the past," says Finger of Starlab Space.

But there is certainly room for broader innovations in the future, as aspirations grow beyond Earth orbit. "The systems we're designing today are focused on low-Earth orbit and the moon," says Buckley. "I see those same systems being used as we go to deep space, to Mars and beyond." ★

Acting Editor-in-Chief Cat Hofacker contributed.

▲ Vast in February began tests of the qualification article of the primary structure of its Haven-1 station, shown here in an illustration. To shorten the development timeline, the SpaceX Crew Dragon capsule that will ferry the four-person crew to Haven-1 will supply life support functions including CO_2 removal.

Vast

Why you need to protect your AI-based inventions

Spurred by artificial intelligence, the aerospace industry is poised to rapidly accelerate the pace of tech development. Companies that fail to safeguard their AI-based inventions stand to miss out on the full benefits. Attorneys from the Washington, D.C., law firm Sterne, Kessler, Goldstein & Fox explain.

BY MICHAEL NATHANSON, MIKE D. WEBB AND GRAHAM C. PHERO

Intellectual property protection has long been intertwined with aerospace innovation, dating at least as far back as the Wright brothers' famous patent dispute with Glenn Curtiss in the early 1900s. Today, breakthroughs in artificial intelligence are ushering in a new wave of technological advancement, just as the breakthrough at Kitty Hawk spurred rapid advancements in aircraft designs in the early 20th century. In fact, while only about 30 years separated the Wright Flyer and the introduction of the Douglas DC-3, widespread investment in AI and the ability to sell AI products independent of manufacturing may accelerate innovation from decades to years or even months.

From startups to established players, aerospace companies are swiftly incorporating AI to increase airspace safety, create advanced autonomous systems, provide critical mission analytics and monitoring capabilities, and improve product validation and verification. In the race to secure their footing in these emerging — and increasingly crowded — fields, some companies might neglect to secure IP protection for innovations and may therefore find themselves blocked out of future opportunities. Indeed, a well-rounded IP portfolio covering AI-based technologies, including utility patents, design patents and trade secrets, will protect shareholder value, provide distinct revenue streams and increase valuations.

Here are the options and their distinct benefits:

Utility patents: protecting novel functionality

Many aerospace companies are pursuing utility patents to secure the functional aspects of AI-based innovations. For example, Reliable Robotics of California filed a patent application in November 2023 that discloses using a computer-vision machine learning model to estimate an aircraft's relative position and corresponding uncertainty to improve autonomous navigation. The navigational system assesses images, applies various functions with trained weights and parameters to identify information in the pixels of image, and then uses the functions and information to generate a reconstructed image.

As another example, in February 2023, Alphabet subsidiary Wing Aviation patented its invention of a neural network model that determines whether an electric vehicle is able to complete a flight without recharging one or more batteries. The system uses training data from a wide array of battery types such that only a single model is needed to assess all types of vehicle batteries with multiple characteristics, even battery types not included in the training data. The resulting system makes the machine learning model more robust and accurate for predicting range.

Such inventions are certainly not limited to aircraft. In late 2023, Slingshot Aerospace disclosed using its machine learning methods and neural networks to prevent collisions between space objects, including satellites, debris, asteroids and rockets. Around the same time, 3D-printed rocket engine manufacturer Relativity Space described, in a patent application, its various systems leveraging machine learning, neural networks and deep networks to predict material properties and assess quality at various stages of the 3D printing process.

Applications like the above are becoming more and more common, but the U.S. Patent and Trademark Office so far remains reticent to grant rights to inventions that generically apply AI algorithms to existing systems. Accordingly, it is important for aerospace companies seeking utility patents on AI-based inventions to address unique qualities of their AI algorithms.

Michael Nathanson is a patent agent and licensed pilot with prior technical experience developing airborne collision avoidance systems.

Mike D. Webb is a patent attorney and former chief of technology at Rolls-Royce, where he specialized in turbine design, structures and transmission components.

Graham C. Phero is a patent attorney and licensed pilot with extensive experience drafting and litigating patents in the aerospace and mechanical arts. He is an AIAA member.

▲ The first flight of a Douglas DC-3 (top) was 32 years to the day after the Wright brothers' flight of the first heavier-than-air craft in 1903 in Kitty Hawk, North Carolina.

Boeing/U.S. National Park Service

Describing inputs, processing and interoperability unique to the aerospace environment and a specific problem (e.g., space debris collection, airborne collision avoidance, fault detection) can help secure enforceable patent rights.

Design patents: protecting aesthetic features

Going hand in hand with improved functionality, aerospace companies are also developing corresponding human-machine interfaces that can be protected by design patents in addition to, or alternatively from, utility patents. While utility patents protect functional inventions, design patents protect how a product looks.

In some cases, aerospace companies known for developing AI-based technology appear to be filing design patents showing interfaces that may be used to display output from their AI tools. Palantir, headquartered in Denver and known for using AI to enhance aircraft manufacturing and development, has obtained more than 30 design patents for user interfaces, including particular icons and transitions. Meanwhile, Thales, a French company with a U.S. presence, is using AI for commercial air traffic management and large drone control and has design patents illustrating cockpit lighting and animated user interfaces.

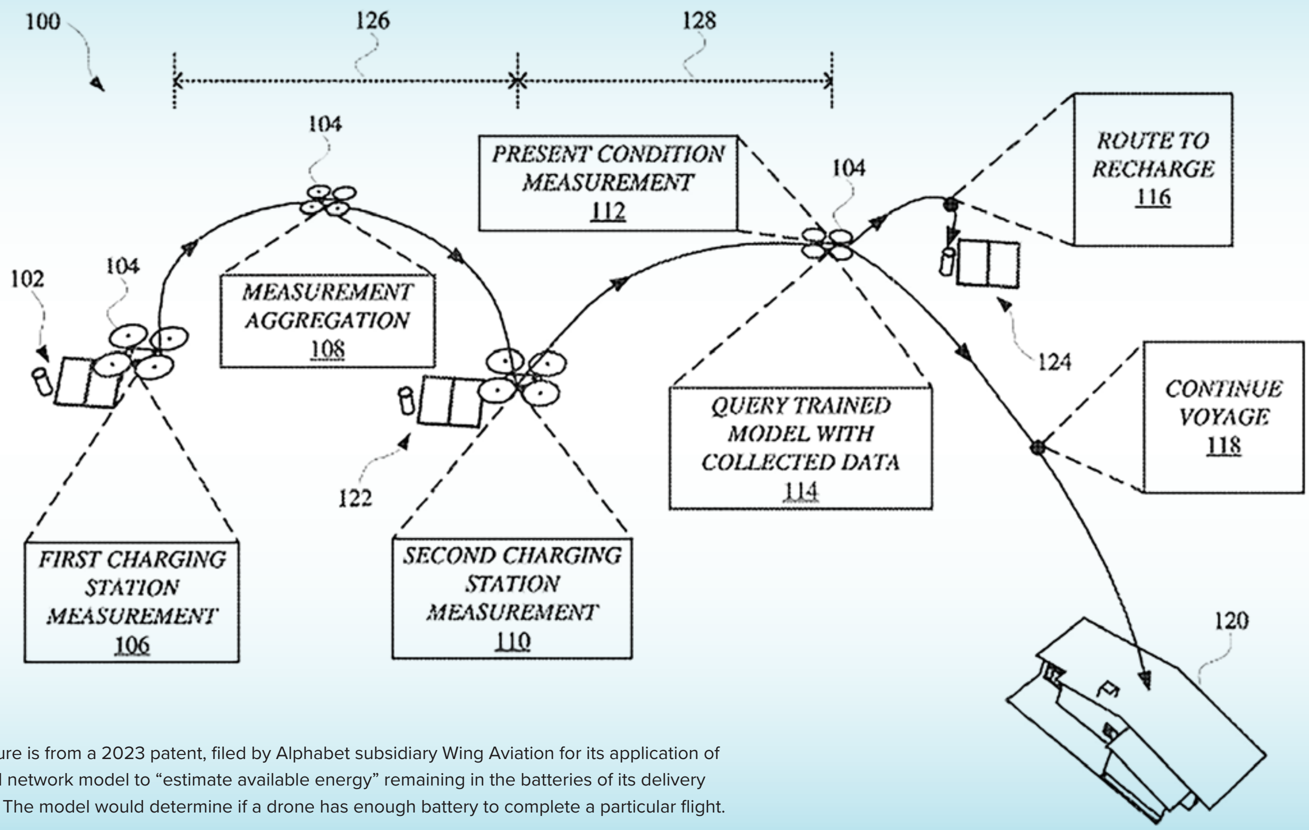
A combination of utility and design patents can efficiently protect and allow companies to commercialize multiple aspects of a product that incorporates AI.

Balancing patents and trade secrets

Trade secrets offer yet another form of IP protection, one that is complementary and often supplemental to patents. These can include inventions, similar to patents, but may also include technical information like training data for a machine learning algorithm and test results. Trade secrets can also include business information, such as market studies and customer lists. Broadly, trade secrets are information that provides an economic advantage because it is secret — a key difference to patents, which require public disclosure.

Often, aerospace products are covered by both patent and trade secret protection. A company may opt to patent a technology that uses a machine learning model to, for instance, estimate a satellite's position, but then also leverage trade secret protection to keep training data and specific parameters from public view.

In some cases, trade secrets may be a preferable



This figure is from a 2023 patent, filed by Alphabet subsidiary Wing Aviation for its application of a neural network model to "estimate available energy" remaining in the batteries of its delivery drones. The model would determine if a drone has enough battery to complete a particular flight.

United States Patent No. 11,592,824

alternative to patent protection because they do not require a formal application or examination and can therefore be cheaper to obtain. However, the key to maintaining a trade secret is actually keeping it secret. This can be particularly difficult in aerospace sectors subject to high employee turnover. Further, simply stating that an innovation is a "trade secret" may not be enough. Establishing an effective, enforceable, trade secret typically requires unambiguously identifying it early in development, restricting access on a need-to-know basis, employee training and strong employment agreements.

Last year's conclusion of the Boeing-Zunum Aero lawsuit illustrates this difficulty. A jury originally ruled in favor of Zunum, a Washington state startup that in 2020 alleged Boeing stole its technology for powering electric aircraft. But three months later, the presiding judge overturned the jury's verdict and Zunum's payout of $72 million. The judge reasoned Zunum did not identify the alleged trade secrets in sufficient detail, nor did it prove that the trade secrets derived economic value from being secret.

Ultimately, a robust and actively implemented trade secret identification and maintenance program can help protect valuable information from walking out the door. And at a higher level, a tailored balance of patents and trade secrets can form a valuable IP portfolio that can protect aerospace companies and provide various commercialization options.

Minimizing risk and increasing value

As the industry continues rapidly developing AI-based technology, neglecting IP protection may leave both startups and established companies open to infringement suits without a counter. This can drain internal resources and deter commercial and government customers.

Proactively filing for patents and securing trade secrets can guard against this. For example, California defense startup Anduril explained in an article on its website that its "patents are not about restricting other companies from building similar non-infringing technology, but for ensuring [its] ability to serve its customers."

Companies can also license their IP, including patents and trade secrets, to introduce additional revenue streams distinct from product manufacturing and sales. This can be particularly valuable for startups that lack massive manufacturing resources or funding. In addition to providing revenue for continued development, licensing opportunities accelerate innovation and the introduction of new technologies into the public.

Additionally, a well-developed IP portfolio generally increases valuations, as investors are typically more confident in companies that have taken steps to minimize risk and have opportunities for multiple revenue streams.

Ultimately, as AI advancement continues to proliferate, the companies that prioritize conscious and deliberate IP protection will be better positioned to succeed and stand out amid a crowded technology field. ★

Addressing the U.S. Aerospace Engineering Shortage

Analysts Weigh in on the Skill and Knowledge Gap from an Aging A&D Workforce and the Impact of AI

Attracting and retaining aerospace talent is getting challenging in today's tight labor market as defense priorities spur more demand for aerospace engineering professionals. The International Trade Administration reports that the U.S. aerospace industry employs approximately 550,000 workers across various occupations, including aircraft manufacturing, rotorcraft, and commercial space sectors.

As the aerospace and defense (A&D) workforce continues to age and retire, employers are left with critical skills and knowledge gaps, according to McKinsey & Company. Deloitte reports the retirement age and attrition rate in A&D is almost 10% higher than the national industry average.

How costly is this talent drain? Andy Voelker, associate partner for McKinsey's Aerospace & Defense Practice, notes the cost can be as high as $300–$330 million for one medium-sized company.

Challenge of Retaining Managers

McKinsey's 2024 A&D talent gap report noted that frontline and middle manager are two times more likely to leave their employer than individual contributors. That's concerning given that about one-third of all A&D manufacturing and engineering roles are filled by workers who are 55 or older.

"The gaps within the workforce are actually greater than what we were seeing pre-Covid," says Lindsey Berckman, leader of Deloitte's U.S Aerospace & Defense Practice. "Despite volatility worldwide there are more job openings than employees in commercial aerospace. Defense budgets are also growing to support the increase in global conflicts."

According to Deloitte's 2025 Aerospace and Defense Industry Outlook, the A&D sector continued to experience talent attraction and retention challenges in 2024, persisting into 2025. One OEM estimates the U.S. commercial aerospace segment alone could require an additional 123,000 technicians in the next two decades.

AIAA Aims to Connect Employers with Engineering Talent

AIAA provides professional development, networking, and career opportunities for aerospace professionals throughout their career arc.

To help its Corporate Members better navigate the retention issues and increasing talent shortage of engineering talent, AIAA is accelerating its efforts to support their recruiting.

AIAA will feature a special recruiting section in its Aerospace America magazine in July. Jobs will be added online throughout August and September. Corporate Members will receive 30 days of complimentary access to upload their available jobs into the AIAA Career Center, a $300 value per posting.

Students from AIAA's 253 student branches have been invited to post their resumes on the Career Center. Job seekers can post their resumes free of charge, including non-AIAA members.

AIAA is uniquely positioned in the aerospace community as a trustworthy partner. We want job seekers to use our Career Center as their prime location for finding new opportunities.

For more information about AIAA's recruitment campaign, visit http://aiaa.org/righthire.

"Our Corporate Members tell us there are not enough people studying engineering to fill the jobs of the future," says Vickie Singer, senior director of Revenue Development and Corporate Membership for AIAA, the world's largest technical society dedicated to the global aerospace profession. She observes that recruitment efforts intensify in the fall as AIAA Corporate Members begin looking to fill internships.

"Companies are looking for specific skill sets. Often the pool of applicants is very limited," she says. "They can get connected through AIAA. We are more than just a broad network; people know who AIAA is."

A key target for companies year-round is mid-career professionals, she adds. This group is harder to retain, driven by changing views of work by the younger and older A&D workforce.

"Our research shows that the degree of work expectations has changed dramatically," explains Voelker. Managers often find themselves leading teams of young engineers who "come in and out of organizations at a much faster rate, so it feels a lot more fluid," Voelker observes. "Entry-level engineers want quicker, faster, more meaningful impact. They want to understand where they are in terms of career progression."

These workplace culture shifts highlight the need for companies to be creative about how they address attracting and keeping top talent. "Aerospace companies don't win with people who come in and out in a few years," notes Berckman with Deloitte. The most innovative companies provide pathways to reward performance across all levels of the organization.

The AI Factor

AI is also a major influence on workforce trends. According to McKinsey's Voelker, "if you look at the expected growth of every occupation group and you look at the impact generative AI is going to have, STEM occupations are by far the biggest single category that is going to be impacted," he states.

By 2030 a significant portion of the entire economy will be automated. Advances from AI and automation will require rethinking how engineers perform their jobs. "The industrial base in the U.S. is trying to figure out what this is going to mean. What skills will matter in the future?" explains Voelker. "The research suggests that the role of engineers will need to be rethought."

Deloitte's Berckman sees AI capabilities as an avenue for empowering top talent and helping to retain them. "AI creates new opportunities to be able to support your workforce and your teams. It will empower everyone to have new insights around how to create and how to make," she says. "For example, defense organizations are using digital threads to connect all the stages of a product lifecycle to enhance collaboration and traceability, enabling them to "implement insights from soup to nuts."

More immediate benefits of AI will lead to automation of more manual tasks, like drawing and proofing engineering designs, says McKinsey's Voelker, allowing engineers to focus more of their time on developing new solutions to problems that automation and digital engineering will deliver. ★

ABOVE + BEYOND

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

BETA

On 3 June, BETA Technologies became the first U.S. all-electric aircraft to land at one of the three major airports in the New York-New Jersey region with the arrival of BETA's ALIA conventional take-off and landing (CTOL) aircraft at JFK International Airport. The ALIA aircraft is one of a new generation of AAM aircraft, often electric and capable of vertical or short takeoff and landing.

PHOTO: BETA TECHNOLOGIES

ROCKET LAB

Rocket Lab's "Full Stream Ahead" mission lifted off from its Launch Complex 1 in Mahia, New Zealand, at 11:57 a.m. NZST on 3 June, successfully deploying a Gen-3 satellite by BlackSky to a 470 km circular Earth orbit and further expanding the company's low Earth orbit constellation. This was Rocket Lab's 65th Electron rocket.

PHOTO: ROCKET LAB

From the Institute

JULY-SEPTEMBER | AIAA NEWS AND EVENTS

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2025			
15 Jul	Aerospace Perspectives Series: Uniting Simulation and Requirements	ONLINE (aiaa.org/events)	
20 Jul	AIAA Regional Leadership Conference	Las Vegas, NV	
21–25 Jul	AIAA AVIATION Forum	Las Vegas, NV	21 Nov 24
22–24 Jul	ASCEND Powered by AIAA	Las Vegas, NV	21 Nov 24
10–14 Aug*	AAS/AIAA Astrodynamics Specialist Conference	Boston, MA (https://www.space-flight.org)	
25 Aug–1 Oct	Orbital Mechanics and Mission Simulation Course	ONLINE (learning.aiaa.org)	
2 Sep–2 Oct	Rotorcraft and Propeller Aerodynamics and Aeroacoustics Course	ONLINE (learning.aiaa.org)	
3–4 Sep	Fundamentals of Space Domain Awareness Course	ONLINE (learning.aiaa.org)	
8 Sep–13 Oct	Machine Learning for Aircraft Applications Course	ONLINE (learning.aiaa.org)	
9–18 Sep	Aircraft Reliability & Reliability Centered Maintenance Course	ONLINE (learning.aiaa.org)	
12 Sep	AIAA Rocky Mountain Section's Annual Technical Symposium	Colorado Springs, CO	27 Aug 25
14–19 Sep*	International Electric Propulsion Conference	London, UK (electricrocket.org)	1 Mar 25
15 Sep–22 Oct	Spacecraft Design, Development, and Operations Course	ONLINE (learning.aiaa.org)	
16 Sep–9 Oct	Hypersonic Aerothermodynamics Course	ONLINE (learning.aiaa.org)	
22 Sep–12 Nov	Design of Gas Turbine Engines Course	ONLINE (learning.aiaa.org)	
22–25 Sep	Space Domain Awareness Course	ONLINE (learning.aiaa.org)	
23–25 Sep*	42nd International Communications Satellite Systems Conference (ICSSC) and its Colloquium	Barcelona, Spain (2025.icssc.space)	
29 Sep–3 Oct*	75th International Astronautical Congress	Sydney, Australia (iac2025.org)	28 Feb 25
30 Sep–23 Oct	Fundamentals of Astrodynamics for Space Missile Defense Course	ONLINE (learning.aiaa.org)	
6–9 Oct	Space Domain Cybersecurity Course	ONLINE (learning.aiaa.org)	
7–23 Oct	Aerodynamic Interactions in Multi-Propeller Aircraft Configurations Course	ONLINE (learning.aiaa.org)	
14–23 Oct	Weapons Bay Cavity and Store Separation Course	ONLINE (learning.aiaa.org)	
20 Oct–5 Nov	Space Architecture Course	ONLINE (learning.aiaa.org)	
21 Oct–18 Nov	Scramjet Propulsion Course	ONLINE (learning.aiaa.org)	

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2025			
21 Oct–11 Nov	Fundamentals of Python for Engineering Programming and Machine Learning Course	ONLINE (learning.aiaa.org)	
25–26 Oct	SmallSat Education Conference	Cape Canaveral, FL	1 Aug 25
28 Oct–20 Nov	V/STOL Aircraft Design Conderations Course	ONLINE (learning.aiaa.org)	
3–6 Nov	Foundations of CFD with OpenFOAM Course	ONLINE (learning.aiaa.org)	
3–7 Nov*	COSPAR 2025 Symposium	Nicosia, Cyprus (cospar@cosparhq.cnes.fr)	4 Apr 25
4–6 Nov	Launch Vehicle Coupled Loads Analysis Course	ONLINE (learning.aiaa.org)	
5–6 Nov	Fundamentals of Space Domain Awareness Course	ONLINE (learning.aiaa.org)	
11–19 Nov	Technical Writing Essentials for Engineers Course	ONLINE (learning.aiaa.org)	
17–20 Nov	Applied Model-Based Systems Engineering Course	ONLINE (learning.aiaa.org)	
1–2 Dec	AIAA Region VII Student Conference	Sydney, Australia	
2026			
12–16 Jan	AIAA SciTech Forum	Orlando, FL	22 May 25
7–14 Mar*	IEEE Aerospace Conference	Big Sky, MT (www.aeroconf.org)	
17–20 Mar	AIAA DEFENSE Forum	Laurel, MD	14 Aug 25
28 Apr	AIAA Fellows Induction Ceremony and Dinner	Washington, DC	
29 Apr	AIAA Awards Gala	Washington, DC	
19–21 May	ASCEND 2026 Powered by AIAA	Washington, DC	
8–12 Jun	AIAA AVIATION Forum	San Diego, CA	
1–9 Aug*	46th Scientific Assembly of the Committee on Space Research (COSPAR 2026) & Associated Events	Florence, Italy (cospar2026.org)	

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.).

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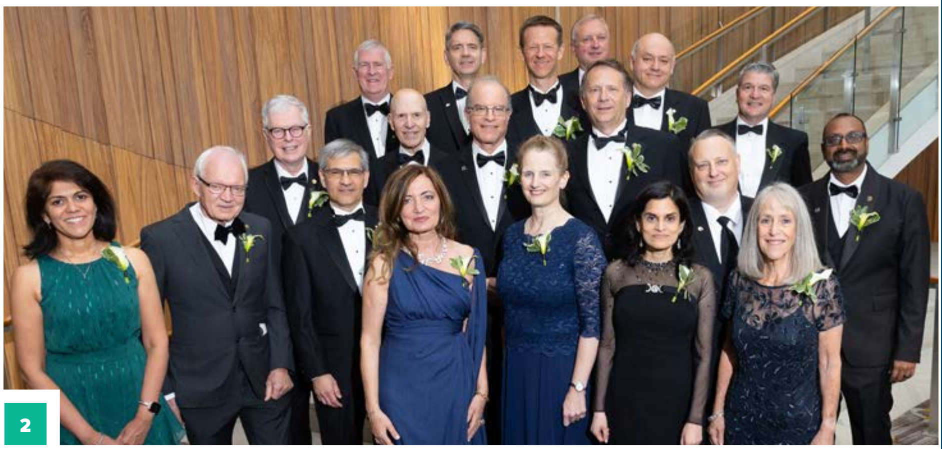

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2025 AIAA Awards Gala Held in April

AIAA presented its premier awards at the AIAA Awards Gala, 30 April, at Grand Hyatt Washington in Washington, DC. The Class of 2025 AIAA Fellows and AIAA Honorary Fellows also were recognized.

1 Class of 2025 AIAA Honorary Fellows: (left to right) Maj. Gen. Charles F. Bolden Jr., USMC (Ret.), Alec Gallimore, and The Honorable Steven J. Isakowitz.

2 Class of 2025 AIAA Fellows.

3 AIAA President Dan Hastings (left) and AIAA CEO Clay Mowry (right) with Hitoshi Kuninaka, recipient of the AIAA International Cooperation Award.

4 AIAA CEO Clay Mowry (left) and AIAA President Dan Hastings (right) with John Couluris, Senior Vice President of Lunar Permanence, Blue Origin, who received the AIAA Goddard Astronautics Award on behalf of Jeff Bezos.

5 Tim Lieuwen, Georgia Institute of Technology (left), and AIAA President Dan Hastings and AIAA CEO Clay Mowry (right) with Vigor Yang, recipient of the AIAA Reed Aeronautics Award.

6 AIAA President Dan Hastings and Sivaram Gogineni, Chair of the 2025 Guggenheim Medal Board of Award (left), and AIAA CEO Clay Mowry (right) with Stephen W. Tsai, recipient of the Daniel Guggenheim Medal.

7 Lesley Weitz, Chief, AIAA Technical Activities Division, and AIAA President Dan Hastings (left) and AIAA CEO Clay Mowry (right) with Christopher J. Ruscher, recipient of the AIAA Engineer of the Year Award.

8 AIAA President Dan Hastings and Nancy Andersen, AIAA Board of Trustees (left) and AIAA CEO Clay Mowry (right) with Gökçin Çınar, recipient of the AIAA Lawrence Sperry Award.

9 Mark Lewis, Purdue Applied Research Institute, and AIAA President Dan Hastings (left) and AIAA CEO Clay Mowry (right) with Bhavya Lal, recipient of the AIAA Public Service Award.

10 AIAA President Dan Hastings and Laura McGill, AIAA Foundation Chair (left), and AIAA CEO Clay Mowry (right) with Basil Hassan, recipient of the AIAA Distinguished Service Award.

11 2025 AIAA Roger W. Kahn Scholarship recipients (l to r): Sowmya Venkatesh, Farrah Berry, Kazi Afra Saiara, and Logan Speight.

12 2025 Trailblazer STEM Educator Award recipients, Kevin L. Simmons, Kelsy Achtenberg, Allan Miller, with AIAA Foundation Chair Laura McGill and AIAA President Dan Hastings (left) and AIAA CEO Clay Mowry and Challenger Center President and Executive Director Mike Kincaid (right).

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DIRECTORY

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We are frequently asked how to submit articles about section events, member awards, and other special interest items in From the Institute. Please contact the staff liaison listed above with Section, Committee, Honors and Awards, Event, or Education information. They will review and forward the information to the From the Institute Editor.

“Oldest Airfield in the World” Designated as AIAA Historic Site

Otto Lilienthal’s 1894–1896 glide flights were honored in a ceremony designating Gollenberg Hill, Germany, as the “oldest airfield in the world” by AIAA on Saturday, 24 May. The ceremony included AIAA members, local community members, and representatives from the German Aerospace Center (DLR).

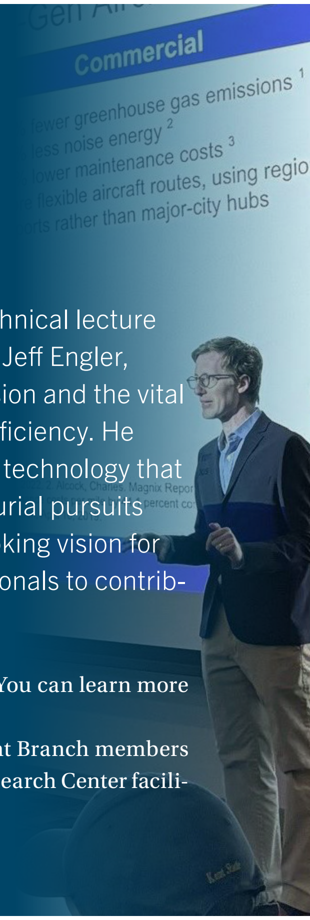
On the occasion, AIAA President Dan Hastings said, “The Institute strives to honor the bold people and memorable places of history that led to modern flight in the atmosphere and beyond the Kármán line. Lilienthal’s breakthroughs laid the decisive foundation for motorized flight over the air. His work directly inspired the Wright brothers and shaped the future of aviation.”

The AIAA Historic Aerospace Sites program recognizes geographical locations, with or without buildings or facilities, associated with significant aerospace achievements, programs or individuals.

Learn more about AIAA Historic Aerospace Sites

Distinguished Lecture Explored Hybrid-Electric Aircraft Propulsion

By Santino Bianco, AIAA Northern Ohio Section



On 25 March, the AIAA Northern Ohio Section (NOS) held a distinguished technical lecture at Kent State University (KSU) College of Aeronautics and Engineering (CAE). Jeff Engler, chief operating officer of Wright Electric, discussed electrified aircraft propulsion and the vital role this technology can play in reducing emissions and enhancing aviation efficiency. He explored the key technological innovations in propulsion systems and battery technology that address longstanding industry challenges, while also highlighting entrepreneurial pursuits and strategic opportunities arising from this evolution. Outlining a forward-looking vision for sustainable innovation, Engler emphasized avenues for students and professionals to contribute to this dynamic field.

Wright Electric is developing megawatt-scale electric machines and batteries for hybrid-electric and all-electric aircraft applications. The company's goal is to make all regional single-aisle flights zero-emissions. The technology is being tested in collaboration with NASA, Department of Energy, and Department of Defense, with plans to have their first plane ready by 2027 for one-hour flights between cities. You can learn more about the company at **weflywright.com**.

In a related activity, 17 AIAA Kent State Student Branch members were given the opportunity to tour NASA Glenn Research Center facilities with members of the NOS Council.

AIAA Continues to Expand Its Reach with New Student Branches

AIAA is excited to announce that seven new student branches were provisionally chartered at the AIAA Spring Business Meetings. The universities include:

- Prince Mohammad Bin Fahd University (Saudi Arabia)
- University of Massachusetts Amherst
- University of New Orleans
- University of Petroleum and Energy Studies (India)
- Western Colorado University
- Kent State University
- National University of Sciences and Technology (Pakistan)

We also welcomed seven student branches in January.

- Institut Teknologi Bandung (Indonesia)
- King Abdulaziz University (Saudi Arabia)
- M.S. Ramaiah University of Applied Sciences (India)
- Military Institute of Science and Technology (Bangladesh)
- Southern Illinois University Edwardsville (United States)
- TED University (Turkey)
- University of Luxembourg (Luxembourg)

"It's an exciting moment as we welcome these new student branches to AIAA. By expanding our global network, we're strengthening international ties and enriching the contributions to our community. We're eager to see the impact these future leaders will have on the aerospace industry," said AIAA CEO Clay Mowry.

The universities have a three-year period to ensure they are a sustainable branch before being officially chartered as a student branch. To find out how your institution can establish a student branch, visit **aiaa.org/get-involved/university-students/student-branches** or contact Lindsay Mitchell at lindsaym@aiaa.org or 703.264.7502.

Largest-Ever DBF Fly-Off Gives Students Real-World Experience

The 2025 Design/Build/Fly (DBF) competition had the largest-ever fly-off participation, with more than 1,200 students on 97 university teams attending onsite. The fly-off, hosted by AIAA Corporate Member RTX in Tucson, AZ, took place 10–13 April. Teams from 14 countries and 34 U.S. states participated in the full DBF competition, including submitting design reports and attending the fly-off.

2025 DBF winners: (l to r) Royal Melbourne Institute of Technology, FH Joanneum, and Santa Clara University.

This year's flight objective was to design, build, and test an airplane to execute an X-1 Supersonic Flight Test Program, including the launch of an X-1 test vehicle — an autonomous glider with flashing lights. Teams also conducted a timed ground mission demonstration of the X-1 Flight Test Program.

The 2025 DBF winners are:

- First Place ($3,000): FH Joanneum, Graz, Austria
- Second Place ($2,000): Royal Melbourne Institute of Technology, Melbourne, Australia
- Third Place ($1,500): Santa Clara University, Santa Clara, Calif.
- Best Report Score ($100): University of New South Wales, Sydney, Australia

Complete results are posted at **aiaa.org/dbf**. The 2026 AIAA DBF Competition will be held in April 2026 hosted in Wichita, KS, by Textron Aviation. For more information on how your organization can engage with and sponsor this event, contact Alexandra D'Imperio, alexandrad@aiaa.org.

READ MORE ABOUT THE FLY-OFF









MAKING AN

IMPACT

AIAA Regional Student Conference Winners Announced

AIAA is pleased to announce the winners of six of the 2025 **Regional Student Conferences**. "We're excited to see our university student members gaining real-life experiences," said AIAA CEO Clay Mowry. "For many students, these conferences are their first opportunity to formally present their research and receive valuable feedback from industry professionals. After hearing several presentations, I came away with a renewed enthusiasm for our community—the future of aerospace is bright indeed."

Record-breaking crowds of over 1,200 students and professionals attended across all six of the recent conferences, and 355 student papers were presented. This year marks the first regional student conference held in Canada. Students had the option to choose to publish their paper with AIAA and they will be available on Aerospace Research Center (ARC; arc.aiaa.org) later this year.

AIAA holds conferences in each region for university student members at the undergraduate and graduate levels, and in some cases high schoolers. The local aerospace industry and universities in the conference cities host tours and sponsor events that, along with the dedication of many local AIAA section volunteers, helps make these conferences a resounding success.

The AIAA Foundation funds the regional student conferences, in addition to contributions from many other regional-level sponsors. The first-place winners in each of the high school, undergraduate, graduate, and team categories (listed below) received cash prizes.

REGION I WINNERS

Undergraduate Category

First Place: "Design and Analysis of a Self-Propelled Nanosatellite for a Mission Beyond Low Earth Orbit," Zoë Jaeger-Letts and Jakub Glowacki, Concordia University (Montreal, Canada)

Second Place: "Structural Analysis and Testing of a Student-Designed UAV Wing," Jack Snyder and Nick Tepylo, Clarkson University (Potsdam, NY)

Third Place: "Visual Exploration with UAVs: Solving the Next-Best-View Problem with Limited A Priori Information," Coleman Henner, Pennsylvania State University (State College, PA)

Graduate Category

First Place: "Advancing Space Situational Awareness: Using Multispectral Imaging for Space Object Observation," Lovejivan Sidhu and Gupreet Singh, York University (Toronto, Canada)

Second Place: "IRMA: New Era for Interstellar Travel," Christina Decker and Felix May, University at Buffalo (Buffalo, NY)

Third Place: "Aircraft Trim Condition Detection Using Flight Test Data and Interval Analysis," Mouhamadou Wade, École de Technologie Supérieure (Montreal, Canada)

Team Category

First Place: "Design of Morph Wings with Tunable Properties for Ultralight Aircraft," Serena Dalo, Emre Danabasoglu, Demi Davis, Benjamin France, Fiona Leitner, Max-well Maria, and James Watson, Worcester Polytechnic Institute (Worcester, MA)

Second Place: "Aerodynamic Performance Enhancement of Co-Flow Jet Airfoil with Metamorphic Wing Mechanism," Rawsen Mitchell, Andrew Leonard, Eric Doraci, and Haifa El-Sadi, Wentworth Institute of Technology (Boston, MA)

Third Place: "Design of a CubeSat Radio Telescope Constellation," Zevulun Lieberman, Sjoerd Huitema, Mary Laurens, Aquil-li Rodriguez Plassa, and Mark Russo, Worcester Polytechnic Institute (Worcester, MA)

REGION II WINNERS

Undergraduate Category

First Place: "Experimental Characterization of a Quadrotor's Response Air Vortex Cannon," Kyle VanHorn, University of North Carolina Charlotte (Charlotte, NC)

Second Place: "Development of a Student-Built LOX/Jet-A Coaxial Swirl Injector," Dario Zaccagnino, Georgia Institute of Technology (Atlanta, GA)

Third Place: "Design and Fabrication of an EDS-Enabled Brush Prototype for Lunar Dust Mitigation," Nishant Sood and Julie Linsey, Georgia Institute of Technology (Atlanta, GA)

Graduate Category

First Place: "Evolution of the Biderectional Vortex in a Capped Ellipsoidal Cyclonic Rocket Engine," Patrick Eid and Joseph Majdalani, Auburn University (Auburn, AL)

Second Place: "On the Multipole Vortex (MpV) Motion in a Circular-Port Hybrid Rocket Engine," Mitchell Sisk and Joseph Majdalani, Auburn University (Auburn, AL)

Third Place: "Star Elimination as a Means of Resident Space Object Identification for Space Situational Awareness," Evan Pavetto-Stewart and Thomas Alan Lovell, Embry-Riddle Aeronautical University (Daytona Beach, FL)

Undergraduate Team Category

First Place: "STARGATE: An Undergraduate Experimental Gridded Ion Thruster Student Research Project," Claude Blue, Peter Summers, Jeffrey King, and Themistoklis Chronis, University of Alabama Huntsville (Huntsville, AL)

Second Place: "Development of a High-Performance Avionics System for Real-Time Guidance and Control in High-Power Vehicles," Cheng Liu, Mohammed Abdeen, and Kanav Chugh, Georgia Institute of Technology (Atlanta, GA)

Third Place: "Design and Analysis of Axial Turbine Power Extraction from a Small-Scale Rotating Detonation Rocket Combustor," Corey Thunes, Donovan Ngum, Ellie Murray, Jose Barbeito, Lucas Nicol, Rodrigo Dacosta, Trevor Larsen and James Braun, North Carolina State University (Raleigh, NC)

Outstanding Student Branch Category

First Place: Auburn University (Auburn, AL)

Second Place: Georgia Institute of Technology (Atlanta, GA)

Third Place: University of Tennessee Knoxville (Knoxville, TN)

Open Topic Category

First Place: "Advancing Laser Communication for Mars Orbital Missions," Om Acharya, Embry-Riddle Aeronautical University (Daytona Beach, FL)

Second Place: "The Orbiter: Pushing the Boundaries of Amateur Rocketry," Yash Malik, Florida Institute of Technology (Melbourne, FL)

Third Place: "A Review of Hypersonic Vehicle Engine Optimization," Nicholas Pisani and Peter Waszkowski, Florida Institute of Technology (Melbourne, FL)

REGION III WINNERS

Undergraduate Category

First Place: "Velocity Characterization of a Newly Commissioned Hypersonic Ludwieg Tube Using FLEET," Rowan Quintero, University of Maryland (College Park, MD)

Second Place: "Free-Flight Testing of Ogive Flare Geometry in Hypersonic Wind Tunnel," Ryan Jones, University of Maryland (College Park, MD)

Third Place: "Continued Development and Validation of an Exoskeleton Focused Immersive Teleoperation Interface," Romeo Perlstein, University of Maryland (College Park, MD)

Graduate Category

First Place: "Multi-Sensor Based Adaptive Fusion Scheme for Position Estimation of Multirotor UAV Systems in GPS-Denied Environments," Luke Busse, University of Cincinnati (Cincinnati, OH)

Second Place: "Cascading Delay Mitigation with Quadratic Bezier Curve Trajectory Planning," Michael Variny, Ohio University (Athens, OH)

Third Place: "Optimization of Thrust Vector Direction for Direct Measurement Uncertainty Minimization," Adam Jones, University of Michigan (Ann Arbor, MI)

Team Category

First Place: "Design and Implementation of a High-Powered Rocket to Investigate Flight Performance and Fin Flutter During Transonic Flight," Sam Zieba, Cesar Martinez, Ian James, Tari Himelhoch, and Cole Christopherson, Milwaukee School of Engineering (Milwaukee, WI)

Second Place: "Mars Autonomous Resupply Constellation (MARC), Raymond Bertke," Hayden Brown, Nicholas Gomori, and Jake Ferris, Ohio State University (Columbus, OH)

Third Place: "Design and Manufacturing of FANG (Fabric ANchoring Gadget) for Fabric Repair on the International Space Station," Zoe Surles, Saanvi Kunisetty, Lillian Hunt, Gabriela Zabiegaj, Ryan Smith, Tiana Foreman, Casimir Palowski, Taranpreet Singh, Alana Falter, Denver Haslett, Andrew Jace Bernando, Kate Pactol, Parker Lenkaitis, Jennifer Ren, Emma Held, and Julia Kalil, University of Illinois Urbana-Champaign (Urbana-Champaign, IL)

REGION IV WINNERS

Undergraduate Category

First Place: "Efficiency of Bio-Inspired Blades for Vertical Axis Wind Turbines," Smruthi Ahashidhar and Kiran Bhaganagar, University of Texas at San Antonio (San Antonio, TX)

Second Place: “Development of a Bimodal Ammonium Perchlorate Cast Propellant for 54-mm and 76-mm Solid Rockets,” Alex Earnhart and Jacob Robinson, Oklahoma State University (Stillwater, OK)

Third Place: “Frequency Response of Fast-Responsive Pressure-Sensitive Paint, Andrew Cervantes and Alexandria Lopez-Boor,” University of Texas at San Antonio, (San Antonio, TX)

Graduate Category

First Place: “Tailoring Metal Particle Deposition on Non-conductive Woven Fabrics for Multifunctional Applications using an Electroplating Process,” Isaac Carney and Isaac Williams, Oklahoma State University (Stillwater, OK)

Second Place: “Development of a Micro-Turbojet Engine Control Unit for Component Level Efficiencies Monitoring,” Zachary Wattenbarger and Kurt Rouser, Oklahoma State University (Stillwater, OK)

Third Place: “An Analytical Model for Thin Film Heat-Transfer Gauges,” Emirhan Bayir, University of Texas at Arlington (Arlington, TX)

Team Category

First Place: “Optimization of Wheel Design for NASA TSGC Lunar Personal Electric Vehicle (LPEV): A Mechanical Engineering Approach,” Akash Musale, Swaid Alrashed, Easton Duplichan, Silas Hill, and Nourouddin Sharifi, Tarleton State University (Stephenville, TX)

Second Place: “Application of Neuromorphic Attitude Control to High-Powered Rockets,” Daniel Bluedorn, Kaiden Kiracofe, Brian Davis, Kimberly Perez, and Stefan Fountain, New Mexico State University (Las Cruces, NM)

Third Place: “Development of a 2-Dimensional, Variable-Area Nozzle for Small Unmanned Aircraft Micro-Turbojets,” Noah Greeson, Andrew Knotts, Sue Ellyn Corbett, Alexandra Boyko, Ryan Berzas, Alexandra Boyko, Tyler Rogalski, and Kurt Rouser, Oklahoma State University (Stillwater, OK)

REGION V WINNERS

Undergraduate Category

First Place: “Modeling Trajectory and Attitude to Optimize Baffle Design for the Optical Navigation System of the Emirates Mission to the Asteroid Belt,” Christopher Michael O’Neill Jr., University of Colorado Boulder (Boulder, CO)

Second Place: “Predictive Station Keeping of Areostationary Satellites Using Natural Motion Trajectories,” Nathan Gall and Ryan Caverly, University of Minnesota (Minneapolis, MN)

Third Place: “Machine Learning Optimization of Model Following Control for Resilient Microburst Attenuation on Final Approach,” Nathan Aldridge and Samuel Stanton, United States Air Force Academy (Air Force Academy, CO)

Graduate Category

First Place: “Long Short-Term Memory Networks to Improve Aerodynamic Coefficient Estimation for Aerocapture,” Dominic Rudakevych and Stephen Becker, University of Colorado Boulder (Boulder, CO)

Second Place: “Hypersonic Glide Vehicle Trajectory Design Using Constrained Energy Maneuverability,” Sam Jaeger and Maziar Hemati, University of Minnesota (Minneapolis, MN)

Third Place: “Human Spaceflight Graduate Projects: Recommendations for Project-Based Aerospace Systems Engineering,” Lynnette Wilde and Lynzee Hogger, University of Colorado Boulder (Boulder, CO)

Undergraduate Team Category

First Place: “Countering Balance Impairments in Microgravity and Earth Environments Using a Reactive Balance System,” Sweta Alla, Maya Mital, and Rishab Pally, University of Colorado Boulder (Boulder, CO)

Second Place: “Sound of Crickets: Design of Experimental System for Analysis of the Effects of Rocket Launch on Acheta domestitcus Cricket Eggs,” Anna Daetz, Bryson Chittum, Aaron Kerber, and William Kilcrease, University of Colorado Colorado Springs (Colorado Springs, CO)

Third Place: “Aerodynamic Stability for Optimal CubeSat Drag Sail Operations,” Adrian Bryant, Polly Fitton, Tyler Renken, Shane Billingsley, University of Colorado Boulder (Boulder, CO)

REGION VI WINNERS

High School Category

First Place: “A Novel Low-Cost Zero Mean-Flow Chamber Design and Physics-Informed Neural Network for Astrophysical and Environmental Turbulence Applications,” Aiden Kwon, Palos Verdes Peninsula High School (Rolling Hills Estates, CA)

Second Place: “A Study of Toroidal Propellers with Comparison to Traditional Propellers," Bingxuan Cheng, Trabuco Hills High School (Mission Viejo, CA)

Third Place: "Taming the Oblique Wing: Improving Fuel Efficiency by Developing and Flight Testing an Oblique Wing Aircraft Utilizing a Novel Control Method," Kevin Shen, Olympia High School (Olympia, WA)

Undergraduate Category

First Place: "Modeling a Gliding Turn-Back Maneuver ("Impossible Turn") Following an Engine Failure," Nicholas Lototsky, University of Southern California (Los Angeles, CA)

Second Place: "Computational Model of a Table Top Shock Tunnel for Hypersonic Environments," Lindsay Feyrer and Tim Linke, University of California Davis (Davis, CA)

Third Place: "Spectroscopic Analysis of Erosion Rate from Electrode Surfaces on the ZaP-HD Device," Elyse Lian, University of Washington (Seattle, WA)

Graduate Category

First Place: "Aerodynamic Force Characterization of a Novel Variable Amplitude Flapping Wing Robot," Geourg Kivijian and Nandeesh Hiremath, California Polytechnic State University San Luis Obispo (San Luis Obispo, CA)

Second Place: "Initial Parametric Design of a Torsion Pendulum to Demonstrate Attitude Control using Microoptoelectromechanical System Control of Radiation Pressure," Jonathan Messer, University of Southern California (Los Angeles, CA)

Third Place: "Influence of Functionalized Titanium Dioxide Ligant Length on Composite Mechanical Properties," Ian Holmes and Joseph Kalman

Undergraduate Team Category

First Place: "Design and Experimental Validation of a Gallium Field Emission Electric Propulsion Thruster," Kylar Flynn, Gabriel Goldman, Connor Storey, and Jose Torres, University of Southern California (Los Angeles, CA)

Second Place Tie: "Tensegrity Structures for Energy Absorption in Aerospace Landing and Reusable Rocket Systems," Leire Roma Rubi, Ryan Kuo, and Brennan Birn, University of California Berkeley (Berkeley, CA)

Second Place Tie: "Load Testing of a Superelastic Tire Suited for Space Exploration," Audrey Park, Jacqueline Nguyen, Amanda Lucker, Yashvi Deliwala, University of Southern California (Los Angeles, CA)

Third Place: "Design of a Non-Flapping Morphing Drone Inspired by the Western Gull," by Jose Aquilera Fuentes, Jeffrey Astorga, Marco Zuloaga, Jeremy LeMaster, Adrian Corral, Jonathan Balan, Joseph Mackey de Zela, Matthew Emil Martin, Harmandeep Gill, Brianna Murphy, and Peter Bishay, California State University Northridge (Northridge, CA)

Obituaries

AIAA Associate Fellow Koshar Died in January 2024

Martin M. Koshar died on 12 January 2024 at the age of 90.

After graduating from Clarkson University in 1955, Koshar joined the Glenn L. Martin Company (which became Martin Marietta and now Lockheed Martin) to begin a long and distinguished career in the defense industry. He worked on multiple nationally significant programs, including TITAN II, Pershing II, ASALM, and LANTIRN fire control system. Koshar directed the Pershing II tactical ballistic missile system, which resulted in the dissolution of the USSR and the end of the Cold War. In 1988, Martin was named president of Martin Marietta's Aero and Naval Systems Division. In a consultant capacity, he supported the U.S. Missile Defense Agency.

AIAA Senior Member Kimberlin Died in November 2024

Ralph D. Kimberlin, Ph.D., respected experimental test pilot, engineer, and graduate professor, died on 28 November 2024. He was 84 years old.

Kimberlin graduated from the U.S. Naval Academy in 1963, and was commissioned as an officer in the U.S. Air Force. He did pilot training at Moody Air Force Base, achieving his first solo in a Cessna T-37. In 1964 at Eglin AFB, he was one of three officers testing weapons systems that included the AC-47 Gunship. This work led Kimberlin to combat evaluations of the aircraft in Vietnam. He also helped design engineer the AC-130 Gunship, recently used by the United States in Iraq and Afghanistan. In 1967 Kimberlin left full-time military service, but he remained in the Air Force Reserves for more than 30 years, retiring in 2000 as a colonel.

Kimberlin worked for aircraft manufacturers Cessna, Beech, Rockwell, and Piper. In 1974, Piper named him their chief of flight test and aerodynamics. In tandem, he earned a Master of Science in aerospace engineering from the University of Tennessee Space Institute (UTSI) in 1975. He knew that his success as a test pilot was tantamount to his engineering knowledge. As an experimental test pilot and aerospace engineer, he logged 9,300+ hours as a pilot across 250 types of aircraft, with 2,250 hours on certification projects that involved 25 first flights. He later earned his Ph.D. in aerospace engineering from the Technical University of Aachen, Germany (1991).

In 1979 Kimberlin became a professor at UTSI in flight test engineering, establishing an academic program for a Master of Science in aviation systems. The program grew to include a flight research center, a hangar, and a dozen airplanes considered flying classrooms. He collaborated with military, government, and civilian flight test programs, as well as working on his own flight testing and research. The U.S. Navy contracted him to test pilot the Ball-Bartoe Jetwing, the only blown-wing airplane in the world, which is now displayed at the Wings Over the Rockies Air & Space Museum.

To document some of what he had learned over his career, Kimberlin wrote *Flight Testing of Fixed-Wing Aircraft* (AIAA, 2003). The book covers performance, stability, and control for propeller-driven and jet aircraft. A final section covers hazardous flight tests, including two tests that forced him to bail out of the aircraft. The book had worldwide distribution and in 2010 it was published in Chinese.

After 27 years at UTSI, Kimberlin retired as an emeritus professor, and alumni distinguished service professor in 2005. He continued to work as a consultant test pilot and flight analyst for 17 more years on projects including the Liberty XL2 development and certification flight tests, the Cessna 208B with hellfire missiles and laser-guided rockets for U.S. Air Force Special Ops, and certification of the Embraer Phenom 300's stabilized camera system positioned under the nose of the aircraft. In 2012, Kimberlin joined the Florida Institute of Technology to help them develop a flight test engineering graduate program. He served as a part-time professor and test pilot instructor during his 12-year tenure.

Among Kimberlin's numerous accolades, the FAA awarded him the Wright Brothers Master Pilot Award in 2022, for his 50+ years of outstanding contributions to aviation safety. In 2014, the Society of Experimental Test Pilots honored him with the distinction of Fellow, their recognition for exceptional test pilots who have made significant contributions to the aerospace industry. After decades of service, AIAA appointed him as chairman emeritus of their Flight Testing Technical Committee.

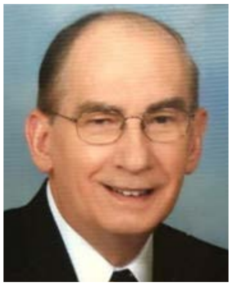
AIAA Associate Fellow Cunningham Died in January 2025

Atlee M. Cunningham Jr. died on 30 January 2025. He was 86 years old.

Cunningham attended the University of Texas in Austin, where he received his Ph.D. in 1966. He also served in the U.S. Navy on the USS Saratoga from 1962 to 1964.

Cunningham then started a position at General Dynamics, now known as Lockheed Martin, working there for over 59 years. He became known throughout the world for his areas of aeronautical expertise including development of steady and unsteady aerodynamic methods, aeroelasticity and buffet prediction methods, wind and water tunnel testing for unsteady flows, and flight testing. Cunningham has two aerodynamics-related patents and taught as a Visiting Industrial Professor at SMU, UT Austin, and UT Arlington graduate schools. Some of his notable accomplishments include design and development on the F-16 and other major aircraft, while also providing his aeronautical experience to NATO, NASA, NTSB, and many other institutions.

Cunningham was also recognized on the Smithsonian National Air and Space Museum's Wall of Honor and with induction into the Worldwide Lifetime Achievement. He also received the NATO/STO Air Vehicle Technology Panel Excellence Award, NASA Certificate of Recognition for a technology publication, and UT Austin Mechanical Engineering Hall of Fame.



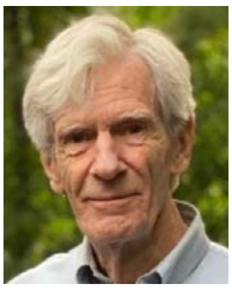
AIAA Senior Member Szaniszlo Died in February 2025

Andrew Szaniszlo died on 13 February 2025. He was 87 years old.

Szaniszlo studied Engineering at Fenn College (now Cleveland State University) before going to work at NASA Lewis Research Center (now Glenn Research Center). He later earned his Master's degree in Physics at John Carroll University.

While at NASA, Szaniszlo conducted a wide variety of research that grew into space experiments, and he contributed to numerous Space Shuttle missions while leading many of these projects. Through his dedication and project excellence, he was nationally recognized and received the prestigious Silver Snoopy Award.

View Obituaries



AIAA Associate Fellow Driscoll Died in March 2025

Richard J. Driscoll Jr. died on 28 March 2025. He was 78 years old.

Driscoll was a highly regarded aerospace engineer, beginning his career with Bell Aerospace and completing it with NASA Goddard Space Flight Center, where he worked on the Europa Clipper. He was a member of the AIAA Liquid Propulsion Technical Committee from 1997 to 2003.

SIMPSON'S VIEW

The honor of defense

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

Over the course of my 40-plus years in aerospace, many students and young professionals have asked me for career advice. For sure, there are exciting opportunities to be had in the commercial world, and many of those companies are a driving force for innovation, but I always urge folks not to overlook the defense sector.

My own experiences prove that one can have a fulfilling career in defense, working on cutting-edge technologies that have the potential to change the world just as much — if not more — than any commercial innovation. But what sets this career path apart is the pride and satisfaction that comes from knowing you are contributing to the protection of your nation and democracy on a global scale. Of course, in a perfect world we would have no need for satellite missile interceptors, fighter jets or anti-aircraft missiles. But as history has continually shown us, ensuring peace and prosperity requires people who are willing to defend our values and way of life against those who would attempt to dismantle it.

When I first entered the aerospace industry in the early 1980s, there was concern that budgets for innovation were trending downward. The U.S. Army had just awarded the "Big Five" production contracts that would reconfigure the service to what it is today. The Air Force was happy with its F-15s and F-16s and new B-1Bs, and the Navy was satisfied with its new F/A-18s. NASA had concluded the Apollo missions, and the space shuttle was nearing its testing phase. Likewise, commercial aviation was anticipating the first flights of the Boeing 757 and 767, while the Douglas DC-9 Super 80 was beginning production. There didn't seem to be anything new on the horizon. However, there was more than enough to keep me occupied, employed and challenged.

My first job was as a summer intern at Hughes Helicopter Inc. doing data analysis on the YAH-64 Apache attack helicopter prototype. I learned about thermal sensors, optical tracking systems, inertial navigation and other systems that were technically advanced for the day, but what stuck with me: the threat of a possible Soviet invasion of Europe with massed tanks through the Fulda Gap in what was then a divided Germany. The Apaches were designed for surprise attacks, with the ability to maneuver around terrain or buildings that could otherwise be used to block their Hydra rockets, Hellfire missiles and chain guns. A year after I departed to go back to school, the Army awarded Hughes a full-rate production contract for the AH-64A.

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.

The technology was undoubtedly cool, but the opportunity to contribute, even indirectly, to the fight against Soviet communism made it all the more satisfying. And, looking back, that went on to influence my priorities for future jobs.

After graduating college, I went to work for Hughes Aircraft Co. (not directly related to Hughes Helicopter, but sort of — another story) in the Electron Dynamics Division. I started as an engineer evaluating traveling wave tubes for the F-14 program that were returned by the U.S. Navy for repair or replacement. Not only did I learn a lot about vacuum tubes and high-power microwave devices, but I was interfacing directly with the Navy customer — probably one of my greatest opportunities to learn nontechnical skills that supported the advancement of my career. Over the next few years, my responsibilities grew, and I took over as the lead engineer for the F-14 Gridded Travel Wave Tube and Continuous Wave Illuminator production programs for the AWG-9 and APG-71 radars. I worked with the production line and actually negotiated with the union to permit me to build one unit at all the stations to better understand the production constraints. With that knowledge, I worked with the drafting department to redesign parts and assemblies to reduce cost and complexity, resulting in a 25% increase in first-time test yield and flow time. This in turn reduced the production cost by 50% per delivered unit. I even visited the F-14 Top Gun facility at Miramar Naval Air Station in California to inspect units in the field. Again, these were all rewarding achievements in and of themselves, but I was all the more motivated knowing that my efforts helped keep F-14s in the air as they protected U.S. aircraft carrier strike fleets around the globe.

The end of the Cold War in the late ’80s seemed to signal another budget reduction, as the predicted “peace dividend” would allow the U.S. to reallocate funds in other areas. The reality, however, was that new types of threats to national and global security emerged, which demanded new technologies for new solutions. High-power vacuum microwave amplifiers, both for airborne radars and satellite communications, were to be replaced with solid state amplifiers. So, a career shift was timely. I transferred to the Hughes Missile Systems Co. to, at first, run captive flight test projects for technologies that would later be incorporated into new weapon systems. For each technology, I was keeping up with advancing expertise and knowledge, but I also knew that I was contributing to the ability for the warriors that protect our nation to do their jobs and come home safely at the end of their mission.

In a later chapter of my career, I had the privilege of serving the American people in several capacities in the Pentagon. It was my responsibility to ensure that not only were the funds entrusted to me appropriately and wisely spent but that the tools we were fielding assisted the soldiers, sailors, Marines, airmen and guardsmen (this was before there were Guardians) in the completion of their assignments. I had the extreme pleasure of working with these dedicated public servants, many of whom became and remain my dear friends. Here again, I was reminded of the importance of this work. These were people who had pledged their very lives to protecting our country and, unfortunately in some cases, were injured or lost their lives in the pursuit of that mission. In each case, their sacrifice was tragic but also served as a vivid reminder of the costs attached to keeping our nation free and safe.

> "As history has continually shown us, ensuring peace and prosperity requires people who are willing to defend our values and way of life against those who would attempt to dismantle it."

Today, while new threats have emerged, opportunities abound. The Trump administration has proposed a 13% increase in defense spending for fiscal 2026, a trend that is projected to continue in the near term as the Defense Department seeks to create the technologies needed for the various tactical and strategic systems necessary for our future defense. Across the Atlantic, defense spending by the European countries has more than doubled over the past several years, with a large percentage of those investments being made in capabilities from the U.S.

I’m proud to have devoted a majority of my career to developing and maturing technologies that protect our nation and our democracy and still believe wholeheartedly that it is a noble cause for young professionals — or anyone at any stage of their career — to contribute their skills, talents and passions. ★

The astronaut who died first: three brothers and a thought experiment

BY MORIBA JAH | moriba@utexas.edu

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.

If you've read my last few columns, you know that the question of our biological compatibility (or lack thereof) with space travel has been on my mind.

Indeed, the technical challenges are daunting — perhaps even insurmountable. (See my January column, "Homo sapiens: making us suited for the stars.") But I know that at the end of the day, that won't stop those who are truly determined to expand humanity's presence beyond Earth. For them, spaceflight is more than a technical achievement; it's the highest expression of our uniquely human drive to understand our place in the cosmos. And, at the end of the day, we all have the freedom to choose how we spend our limited time.

To bring this idea into focus, I offer this parable of three brothers who shared every milestone, every memory, as if proper time flowed equally through them all. Their story illustrates how our experience of time ultimately depends on how much we must adapt and remember:

Once there were three siblings, triplets, born moments apart. They grew up indistinguishable in every way: same home, same food, same books, same memories. They lived as though time were something shared, a rhythm moving through them equally without favor or exception. To be older was to have spent more time alive, and time was something the universe gave you in equal measure.

But that belief would be challenged.

In adulthood, two of the brothers became astronauts and were chosen for a historic mission: separate 50-year round trips to the star Sirius and back, moving at relativistic speeds. One traveled aboard a basic capsule, experiencing microgravity the entire way, save for daily resistance exercises. The other boarded a rotating von Braun wheel, a spacecraft designed to simulate Earth-like gravity through the apparent resistance to centripetal acceleration. The third stayed on Earth, carrying out an ordinary life.

Einstein's theory of special relativity already predicted what would happen next: Time moves slower for those in motion relative to those at rest, so the two traveling brothers would return younger than the one who remained on Earth.

And indeed, when they returned, they had aged less — at least, by the calendar. But one of them was dying.

The problem Einstein didn't solve

The astronaut from the capsule, who had spent five decades in free fall, was breaking down. His bones were brittle. His immune system had collapsed. His muscles had withered. His organs bore the unmistakable mark of accelerated aging. In contrast, his brother from the von Braun wheel was in good health, alert, mobile, resilient. Both had taken the same journey. Both had followed the same relativistic path. Both had measured the same proper time.

So why was only one dying?

Relativity offered no answer. In Einstein's space-time, they had traced identical geodesics. The equations held. But the human body isn't a coordinate or a worldline. It is an engine of adaptation, a system of systems, constantly reacting to its own state and surroundings. It changes to survive. And that change, it turns out, is not free.

Time as distinction

We are taught to think of time as something that passes, like wind across a field. But what if time isn't what happens to us, what if it's what we register? This is the foundation of epistemic time, the notion that time is not a universal ticking but an internal accumulation of distinction. Here, a system such as the human body experiences time only to the extent that it undergoes informational change — that it senses, remembers, adapts.

In this view, time is not something we travel through. It is something we build, one distinction at a time.

For the astronaut in free fall, the experience of space was far from passive. His body was forced to compensate continuously: for fluid redistribution, for bone density loss, for cardiovascular drift, for sensory disorientation. Each adaptation required reorganization. Every system was working overtime just to preserve a sense of normalcy in a profoundly abnormal environment.

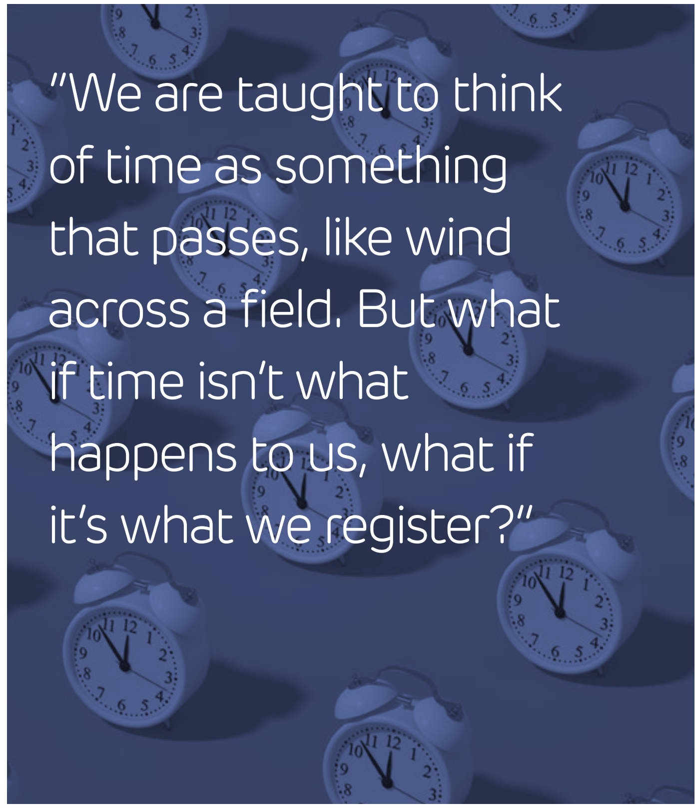
From the standpoint of epistemic time, these compensations were costly. Every change registered by the body, every internal distinction, was a unit of experienced time. So his biological clock was not ticking slower. It was racing ahead.

The astronaut in the von Braun wheel, meanwhile, faced none of these pressures. The artificial gravity mimicked Earth's loading, so his body had fewer adaptations to make, fewer disturbances to resolve. His systems remained closer to homeostasis. In epistemic terms, he aged less, because he experienced less disruption.

Epistemic time is the accumulation of meaningful, internal change. It is not measured by clocks but by the number of distinctions a system undergoes, how much it must adapt, remember or reorganize in response to contrast. If nothing changes, no information is processed. If no information is processed, no time is experienced. In this view, time is not what passes in the universe but what a system registers as difference. A perfect vacuum, a frozen cell or a photon in transit does not experience time unless something internal changes in a distinguishable way. This is why epistemic time can differ radically from both proper time and coordinate time. It is the only kind of time that feels like anything.

Rethinking aging

This is the heart of the paradigm shift. Aging is not just the slow unraveling of DNA, nor merely the entropic march of biology. It is the accumulation of irreversible epistemic transitions, changes that leave a mark. A life of trauma, of constant adaptation, of repeated stress, doesn't just feel longer. It is longer, in informational terms.



The astronaut in the capsule did not age faster because of gravity or acceleration. He aged faster because his body endured a more turbulent stream of informational change. He didn't just survive the journey — he paid for it with epistemic time.

Cryostasis and the clock that doesn't tick

This framework solves another paradox. In traditional relativity, someone in cryostasis, frozen for 500 years, would be called "500 years old" by the calendar. But this is absurd. No internal distinctions were made. No memories were formed. No metabolic changes occurred.

From the epistemic standpoint, this person experienced no time. They are, experientially, as young as the moment they were frozen. Because without information, without difference, without change, time does not exist.

Einstein gave us a way to measure time geometrically. He showed us that time is relative to motion and gravity. But epistemic time shows us that true time is relative to experience. The universe may track your proper time, but your biology tracks how hard you've had to fight for coherence.

The astronaut who died first didn't die because of space. He died because of adaptation overload. Because his systems couldn't hold their shapes against the tide of change. His life wasn't cut short by relativistic mechanics. It was accelerated by informational turbulence. He was epistemically the oldest of the three.

And in this, we see something profound: Time doesn't just pass. It remembers. ★

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LOOKING BACK

100, 75, 50, 25 YEARS AGO IN JULY–SEPTEMBER

COMPILED BY FRANK H. WINTER AND ROBERT VAN DER LINDEN

1925

July 1 The U.S. Air Mail Service begins night service between New York and Chicago. The inaugural flight, which coincides with the first anniversary of the introduction of transcontinental air service, draws approximately 250,000 spectators along the route. With the introduction of night flying, mail can now be delivered between New York City and San Francisco in 29 hours. **Aviation**, July 13, 1925, pp. 38-40; **Flight**, Aug. 27, 1925, p. 555.

1 **Aug. 31** U.S. Navy Cmdr. John Rodgers and his crew set a nonstop distance record in their PN-9 flying boat. They depart San Pablo Bay, California, traveling some 3,205 kilometers toward Hawaii before running out of fuel. They are forced to land in the sea several hundred kilometers short of their destination. Presumed lost, the crew repurposes the plane's components to steer the craft toward land. They are spotted off the island of Kauai nine days later. **Aircraft Yearbook, 1926**, pp. 122-124.

2 **Sept. 3** Violent thunderstorms break up the U.S. Navy dirigible USS Shenandoah over Ava, Ohio, killing 14 of the 43 aboard. The airship was en route to Indianapolis from New Jersey under the command of Cmdr. Zachary Lansdowne. Prompted by this accident and the recent disappearance of the PN-9 seaplane, Col. William "Billy" Mitchell releases a statement to the press alleging that both incidents are the result of "incompetency" and "criminal negligence" by the Navy and War departments. Mitchell is court-marshaled for this statement, and U.S. President Calvin Coolidge appoints the Morrow Board to study and make recommendations on the "best means of developing and applying aircraft in national defense." Carroll V. Glines, **The Compact History of the United States Air Force**, pp. 115-116; **Aviation**, Sept. 14, 1925, pp. 310-315.

1950

July 24 The U.S. Army launches the first rocket from Cape Canaveral, Florida. This Bumper WAC BU8 is also the first U.S. two-stage rocket, consisting of a German V-2 missile first stage and a WAC Corporal sounding rocket as its second stage. U.S. Air Force, **Chronology of American Aerospace Events**, p. 58.

Aug. 24 A RIM-2 Terrier surface-to-air missile intercepts a Grumman F6F Hellcat during a test at the Naval Ordnance Test Station in Inyokern, California. This two-stage solid-fuel design, designed to reach altitudes above 15,000 meters, shows potential for augmenting the U.S. Navy's standard shipboard missiles. **U.S. Naval Aviation, 1910-1970**, p. 183.

Aug. 31 The first mouse is sent to space in a V-2 rocket launched from White Sands Proving Ground in New Mexico. During the flight, which reaches an altitude of 137 kilometers, an on-board camera photographs the mouse to add to the growing body of research centering on the biological effects of high-altitude travel. Willy Ley, **Rockets, Missiles, and Space Travel**, p. 459.

Sept. 22 U.S. Air Force Col. David Schilling and Lt. Col. William Ritchie demonstrate the practicality of aerial refueling for long-range fighter aircraft. They embark on the first nonstop aerial crossing of the Atlantic, flying from Manston, England, to Limestone, Maine, during which their Flying Republic F-84E Thunderjets are refueled three times. Ritchie's F-84 is unable to be refueled a third time, and he ejects over Labrador. Schilling completes the crossing and later receives the Harmon International Trophy. U.S. Air Force, **A Chronology of American Aerospace Events**, p. 58; L.G.S. Payne, **Air Dates**, p.422.

1975

3 **July 15-24** NASA and the Soviet Union conduct the Apollo-Soyuz Test Project, the first international space mission. Planned as a symbol of Cold War cooperation, ASTP also served as a demonstration of the process for a future astronaut rescue. On July 17, astronauts Thomas Stafford, Vance Brand and Donald "Deke" Slayton in their Apollo capsule rendezvous with the Soyuz 19 spacecraft carrying cosmonauts Aleksey Leonov and Valery Kubasov. The capsules remain linked for two days, during which the crews exchange greetings and gifts and broadcast live messages to Earth. Soyuz 19 touches down near the Baikonur Cosmodrome on July 21, the first Soviet landing to be broadcast. The Apollo crew spends an additional three days in orbit before splashing down in the Pacific Ocean. NASA, **Astronautics and Aeronautics, 1975**, pp. 131-136.

July 15 Western Union's Westar 1 and 2 satellites begin commercial video service with the historic broadcast of the Apollo-Soyuz Test Project. Positioned in geosynchronous orbit, the two satellites relay signals to ground stations near major cities. NASA, **Astronautics and Aeronautics, 1975**, p. 136.

July 26 The People's Republic of China launches its third satellite, the 1,107-kilogram Changkong-1. This is the first time China launches a payload heavier than a metric ton and the first successful launch of an FB-1 medium-lift rocket. **Washington Post**, July 28, 1975.

Aug. 4 Intelsat signs an agreement to transfer three of its pioneering communications satellites to the Smithsonian Institution's National Air and Space Museum. The artifacts — a backup model of Early Bird 1, the first commercial communications satellite; a backup model of Intelsat II; and an engineering model of Intelsat III — are to be featured in the museum's inaugural exhibition. Led by Apollo 11 astronaut Michael Collins, the museum is to open in July 1976 to coincide with the bicentennial of the United States. **Intelsat Release**, 75-224.

4 **Aug. 20 and Sept. 9** NASA launches Viking 1 and 2, the identical probes that will become the first U.S. spacecraft to land on Mars. Each Viking consists of a 2,360-kg orbiter and a 1,180-kg lander. Viking 1's landing is targeted for July 4, 1976, to coincide with the U.S. bicentennial. The Viking orbiters are to make observations from orbit while the landers take direct measurements of the atmosphere and on the surface. Chief among the scientific goals is to examine the Martian soil in search of organic materials. **New York Times**, Aug. 18-22, 1975. **Viking Mission Operations Satellite Bulletins** 10-14.

Sept. 17 One of the most detailed and instrumented models of a space shuttle orbiter ever constructed completes extensive wind tunnel testing at the Arnold Engineering Development Complex in Tennessee. The 92-centimeter model is equipped with approximately 835 temperature sensors to measure the heat levels during the jettison process of the two expendable solid-fuel rocket boosters. **Air Force Development Complex Release OIP** 226, 1975.

2000

July 10 EADS, the European Aeronautic Defence and Space Co., is created by the merger of three major aerospace firms: France's Aérospatiale-Matra, Germany's DaimlerChrysler Aerospace AG, and Spain's Construcciones Aeronáuticas SA. EADS is renamed Airbus Group SE in 2015. **Airbus website**, https://www.airbus.com/en/about-us/our-history

5 **July 26** The unoccupied Russian Zvezda service module becomes the third component of the

LOOKING BACK+

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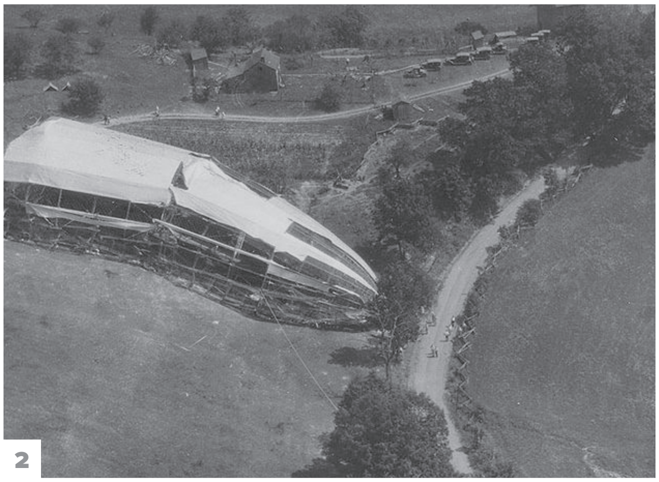
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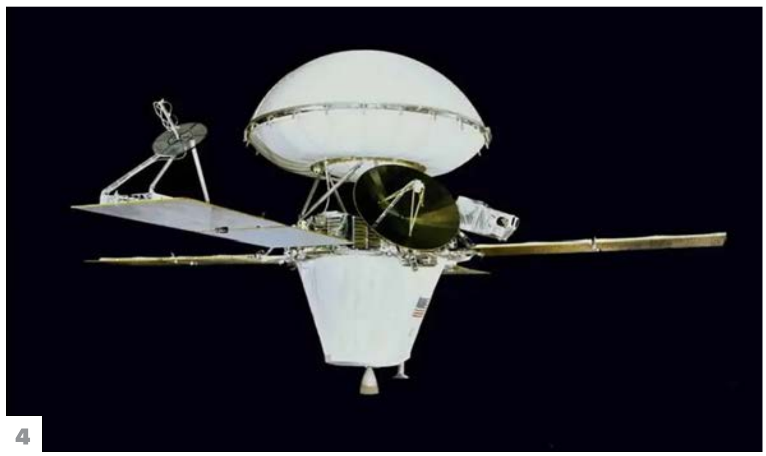
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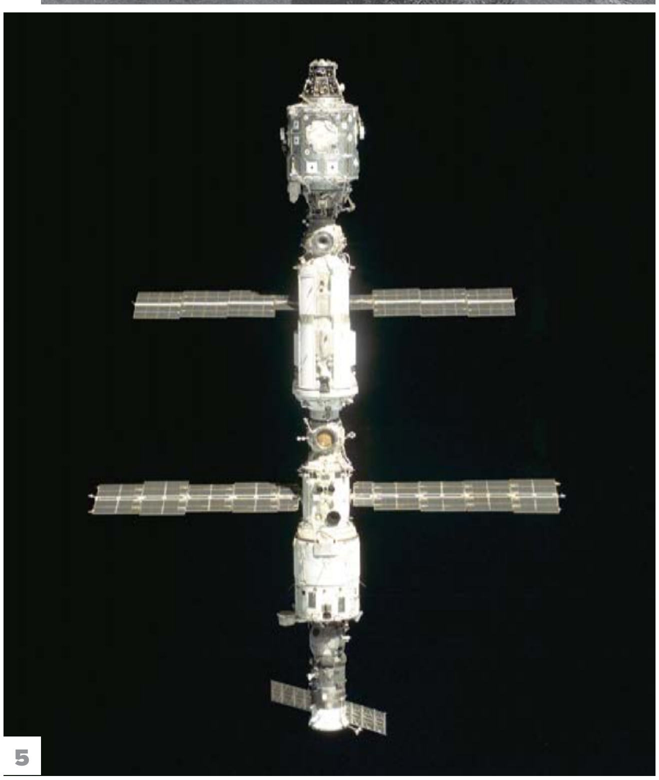
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6

International Space Station, which then consists of the Russian Zarya and U.S. Unity modules. The first cargo resupply vehicle, Progress M1-3, arrives Aug. 8 and the seven-astronaut crew of STS-106 arrives Sept. 8 for an eight-day stay to prepare ISS for its first long-duration crew. **Flight International,** Aug. 1-7, 2000, p. 55, and Aug. 15-21, 2000, pp. 32-33.

Sept. 20 The first Airbus A340-600 prototype rolls out of the factory in Toulouse, France. With a length of 247.5 feet (75.4 meters), it is the longest commercial aircraft ever built. A stretched version of the popular A340, it seats up to 400. **Flight International**, Jan. 2-8. 2001, pp. 48-51; and June 12-18, 2001, pp. 126-132.

6 **Also during September** The French Navy's nuclear-powered aircraft carrier Charles de Gaulle officially becomes operational. Concurrently, the aging aircraft carrier Foch is retired and sold to the Brazilian Navy, which renames it the Sao Paulo. **Flight International**, April 11-17, 2000, pp. 32-33, and Aug. 8-14, 2000, p. 15.

Taylor Fazzini, 30

She may be relatively early in her career, but Taylor Fazzini had already tied on several “hats” before landing her current role as a modeling and simulation engineer for Northrop Grumman Aeronautics Systems. Most recently, she participated in Northrop’s Future Technical Leaders Program, completing one-year rotations on different programs across the U.S. “It was a really good way to explore disciplines outside of my own,” she says.

What’s your aerospace origin story? ▶ I recently found this interview I did for my local paper my senior year of high school, where I said, “I’m going to college to earn a master's degree in aerospace engineering. I hope to work with Lockheed Martin or NASA.” While my husband is the one who’s worked for both NASA and Lockheed Martin, I did end up with the master’s degree and have established a great career in the aerospace and defense industry with Northrop Grumman.

Favorite thing about your job? ▶ A lot of what we do is figure out how to incorporate new capabilities onto planes. So, take the SR-71 as an example: How do we make this thing fly high and fast? Where do we fly that minimizes the risk of our enemies seeing us, or minimizes the risk of us getting shot down, or gives us lots of places with runways to land if something goes wrong, a la Top Gun Maverick’s Dark Star disintegrating over the middle of nowhere? It’s really all about pushing the boundaries of what’s possible, and we’ll never know what works unless we try it out.

What motivates you? ▶ Part of freshman year orientation at Embry-Riddle is watching “Top Gun” in the hangar next to the airplanes. I was giddy the whole time, so I’m constantly chasing the feeling of being absolutely awestruck by how cool military airplanes are; the goosebumps you get when you see a plane that you worked on get airborne for the first time. It’s also important to me to be a support system for anyone who wants or needs it, especially the younger engineers, so I’m constantly working to be the best mentor I can be. The next generation deserves that.

What’s a tech outside your field that fascinates you? ▶ I’m a huge Formula One fan. You have all of these teams with very strict budgets, operating on super limited resources and rapid development cycles. I kind of see it as a tangent sister to aerospace, because it is so focused on aerodynamics and propulsion. I’m also fascinated by food science and food chemistry. That idea of breaking the “rules” is extremely prevalent, where chefs understand the science well enough to understand how it can be manipulated in totally new ways for people to enjoy.

What will the world look like in 2050? ▶ With the massive growth of digital engineering and the infusion of machine learning and AI algorithms, design cycles will be drastically reduced. We’ll get better vehicles in shorter amounts of time, as long as acquisitions and certification figure out a way to keep up. That means it’ll also become increasingly important for students to learn the fundamentals. Anyone can push a button to make a code run, but it’ll still take old-school aerospace engineers to understand if the data coming out makes any sense at all. ★

MORE ABOUT TAYLOR

CAREER HIGHLIGHT: 2020-2023, member of Northrop Grumman’s Future Technical Leaders Program. Completed a one-year rotation in Utah and two in Palmdale, California, working on the Sentinel missile and B-21 Raider bomber, among other programs.

AIAA RECORD: Joined as a student member in 2014 and became a senior member in 2023. Since May, director of the Young Professional Group. Since 2021, member of the Design/Build/Fly organizing committee, Young Professional Group and Aircraft Design Technical Committee. Since 2023, member of SciTech Forum guiding coalition.

EDUCATION: Bachelor of Science in aerospace engineering from Embry-Riddle, 2017; Master of Science in aerospace engineering from Georgia Tech, 2020; Working on her doctorate in systems engineering from Colorado State.

ULTIMATE FAN: “I walked down the aisle to the ‘Top Gun’ theme song at my wedding last year. We got married at the Smithsonian surrounded by airplanes and airplane-loving nerds in front of the SR-71, and we signed our marriage license in front of the space shuttle.”