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AIAA
SHAPING THE FUTURE OF AEROSPACE

In March, an A380 test aircraft similar to this one burned 100% sustainable aviation fuel in one its four Rolls-Royce Trent 900 engines. The fuel was derived mainly from cooking oil and other waste fats.

Airbus

AEROSPACE AMERICA

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AIAA
SHAPING THE FUTURE OF AEROSPACE

IN THIS ISSUE

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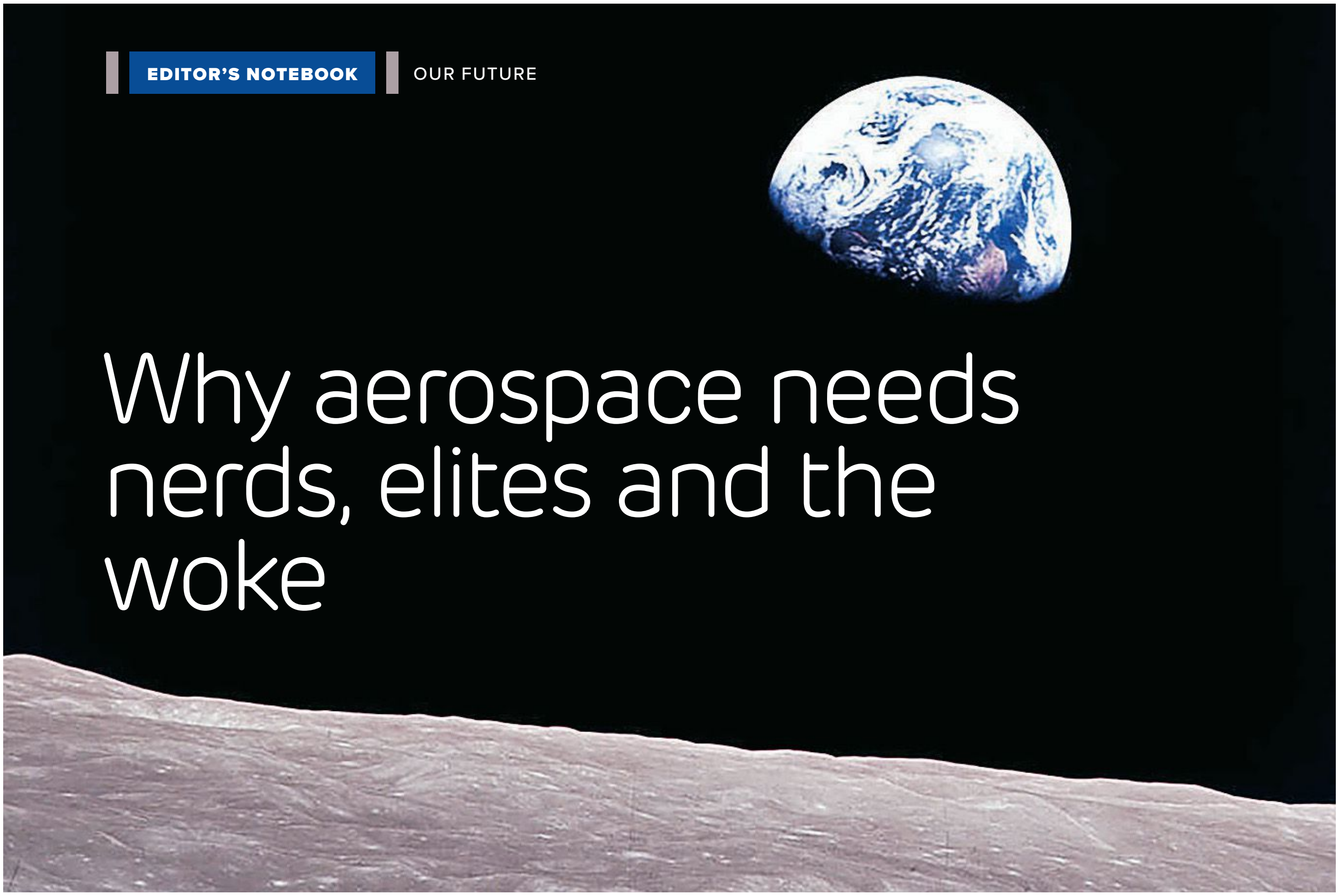
DEPARTMENTS



Why aerospace needs nerds, elites and the woke

If you're passionate about something technical, you're a nerd. If you're among the best at what you do, you're an elite. If you care about the world beyond you, you're woke.

I'll leave it to others to judge our collective penchant for labeling one another. Since labeling is probably here to stay, let me say I'm grateful that the democratic side of the world has nerds, elites and the woke, if that's what people want to call them. We have those categories here at the magazine (I'm not naming names), in AIAA more broadly and throughout the aerospace industry.

Looking at the war in Ukraine, I'm glad Lockheed Martin and Raytheon have engineers who live and breathe the intricacies of automatic guidance, that those engineers are among the best in the world at it and that policymakers were aware enough to the dark side of the human spirit to know that, sadly, deadly weapons like the Javelin anti-armor missiles might someday make the difference for freedom. Here in the United States and in Australia, much the same could be said about the awakening to the need to create air-breathing hypersonic missiles before authoritarian governments do. This month's Engineering Notebook article, "Reducing the need for hypersonic tunnel testing," shows us the kind of basic research that must be done, and fast, for that to happen.

Autocrats are not the only threats to our future. We've created some problems through our love of technology, and some of those we'll need to fix that way too. On climate change, we're seeing an air transportation industry that once downplayed its pollution contributions waking up to the reality that all sectors must do their part. That epiphany is beginning to produce tangible results, as our cover story on sustainable aviation fuel shows. The race is on to see who will emerge as the elites in that field.

On matters of workforce, I'm grateful we're waking up to the fact that our societies include people with diverse gender identities and sexual orientations. When we empower everyone, we make our industries and our governments more powerful. It's about ethics, of course, but it's also a matter of math. Technical excellence and creativity transcend all labels, and by accepting diversity, we maximize those factors on the democratic side of the equation.

Perhaps more than any other factor, this acceptance is how we'll live in a cleaner, safer, more free world. ★

Ben Iannotta, editor-in-chief, beni@aiaa.org

FLIGHT PATH

Rising Above the Storm

Back in January 2020, I left AIAA SciTech Forum in Orlando, Florida, thinking that my next in-person AIAA meeting would be as your president. As it turned out, I did not attend an in-person AIAA event or meeting until two years later, when AIAA SciTech Forum convened in San Diego, California, this past January. What a difference the pandemic made. When I started my term in May 2020 the future held a lot of uncertainty for all of us. The last two years have been a challenge to say the least, but I am certainly encouraged by the future.

Dealing with the uncertainty of the pandemic required us to be both agile in our decision making and also plan for multiple scenarios. Luckily, due to the foresight of prior AIAA Boards of Trustees, the Institute has an investment portfolio where reserves are kept for such a "rainy day." This allowed us to continue to support our operations and provide products to our members and customers. The current AIAA Board of Trustees worked closely with our Executive Director Dan Dumbacher and the rest of the AIAA staff to make sure we made timely decisions that were in the best interest of the Institute, and we also used this opportunity to think about investing for our future.

Starting with the 2020 AIAA AVIATION Forum, we went fully virtual. This mode of virtual events continued for the next year and a half, until we held the first hybrid event, ASCEND, in November 2021. These decisions not only allowed us to continue our all-important information exchange typically enjoyed through in-person events, they also allowed us to connect virtually with those who might not have had the opportunity to travel. The virtual tools allowed us to create a whole new set of online products, including seminars, short courses, and career fairs that have been well received by both members and new customers to AIAA.

One of my goals as president two years ago was to increase AIAA membership and engagement with the broader aerospace community. While we did not see marked growth in professional members during the pandemic, we are seeing increases in student participation, even though much of their engagement has been virtual. Spring 2022 brought the return of the in-person Design/Build/Fly competition and hybrid AIAA Regional Student Conferences. I will take the increased student engagement as a win!

Secondly, I wanted to ensure that AIAA's many products and services remain relevant to the aerospace community. I am especially proud of our volunteer leaders and AIAA staff quickly pivoting to the virtual environment. While we saw some variations in attendance numbers, we kept people engaged. We also held our annual recognition events in a virtual environment to ensure we honored excellence in the aerospace community. In many cases, we saw increased participation. In the end, we could have hunkered down and just waited to weather the storm, but I believe that virtual meeting capabilities are here to stay, and they will nicely complement our more traditional in-person events. And our new AIAA Domain approach, focused on Aeronautics, Aerospace R&D, and Space, will guide all of our products to ensure we provide maximum benefit to each of our customers.

Finally, you had my personal commitment to invest in our future and make AIAA a place where students and young professionals would find a home. During my tenure as President, I personally spoke to over 20 AIAA Student Branches and reached out to several hundred students sharing how AIAA could help enable their professional careers. If traveling was my only option, I would only have been able to reach a fraction of these future leaders. Through programs like AIAA Mentor Match and Diversity Scholars, I was able to impart my knowledge and experience directly to dozens of students and young professional mentees, to inspire them about this prospective career path and guide their future as our next leaders. These experiences were some of the most rewarding of my career.

In closing, I believe that AIAA's future is bright. Through a lot of hard work, we are coming out stronger on the other side. In the last two years, we have seen resilience in our aerospace community as we have seen the expansion of UAVs in the airspace and commercial companies transporting private citizens to space. I am excited for our future! I am also thrilled to work with my longtime friend and colleague, Laura McGill, who will lead us over the next two years as AIAA President. I know that she and the current Board of Trustees are committed to continuing the investment in our future and ensuring that AIAA will continue to be the place of aerospace excellence moving forward. While the path the last two years was certainly not what I envisioned, I appreciate the feedback, dedication, and support from all of you as we continue on this journey. You have my commitment to continue to be there every step of the way as we rise above the current storm. ★

Basil Hassan
AIAA President (2020–2022)

AERO PUZZLER

Do you have a puzzler to suggest? Email us at aeropuzzler@aerospaceamerica.org

Life without flap track fairings

Q: Some aeronautical engineers formed a grunge band called the Flap Track Fairings, and now FTF has become a sensation despite bad reviews from music critics. One of the reviewers writes, “The band is named for a part of an aircraft that is rarely noticed and serves no meaningful purpose. Perfect!” The engineers decide to pen a letter to the editor. What should they say?

SEND A RESPONSE OF UP TO 250 WORDS that someone in any field could understand to aeropuzzler@aerospaceamerica.org by noon Eastern May 16 for a chance to have it published in the next issue.

Get a head start on the June AeroPuzzler: Scan the QR code or follow us @AeroAmMag

FROM THE APRIL ISSUE

“SEEING” DARK ENERGY:

We asked you how Hubble could capture this invisible phenomenon. There was no winner this month, so we asked cosmologist **John Mather** of NASA’s Goddard Space Flight Center to explain:

“Dark energy is invisible, and even giving it a name suggests more than we really know. It was discovered by measuring the brightness of distant supernovae (exploding stars used as standard candles) with the Hubble Space Telescope; they were about 20% fainter than expected. The geometrical explanation is that they are farther away than we thought based on the expanding universe idea that connects the redshift (apparent expansion velocity) with the distance, if we have the right history of the expansion rate. The next step is to say it would be matched by a universe that is speeding up instead of slowing down. Then we saw that the measurements fit perfectly with Einstein’s lambda constant, which he added to his equations to fit his intuition that the universe must be static, even though it isn’t. Curiously enough, the measurements of spots in the cosmic microwave background radiation gives another way to study this acceleration, since gravity acts on the dense regions and stops the expansion locally, leading to the formation of the galaxies. At first, that method agreed very well with the supernova method. But now, improved measurements of the expansion rate are beginning to disagree a little. Now the question for astronomers is does the real universe still match Einstein’s constant, or is the constant not a constant? Does the acceleration come from one or more physical processes we could understand more deeply, or is it just a mysterious constant of nature?”

Coming soon: shirtsleeve EVAs

BY PAUL MARKS | paulmarksnews@protonmail.com

▲ In this rendering, an engineer makes an excursion outside the Orbital Reef space station in the Genesis Single-Person Spacecraft.

Genesis Engineering Solutions

Of all the commercial space station plans, perhaps none would provide a more astonishing on-orbit experience than the Single-Person Spacecraft in which Blue Origin and Sierra Space of Colorado aim to have engineers and tourists fly in from their planned Orbital Reef station later this decade.

Under development by Genesis Engineering Solutions of Maryland, the SPS will allow solo space excursions without a spacesuit. No neutral buoyancy training nor time-consuming preparations for extravehicular activities, EVAs, will be needed.

A spacefarer in shirtsleeves would open an Orbital Reef interior hatch, move into the SPS — pressurized at the same 14.7 pounds per square inch as the station — and close the hatch. An engineer could control the SPS by hand, such as when working on the station's hull, or it could be flown by a teleoperator aboard Orbital Reef. The SPS could also fly autonomously, such as for space tourist excursions.

Comprising a cylindrical shell protected by ISS-grade micrometeoroid orbital shielding, the SPS will be topped by a broad, ultrastrong polycarbonate dome. "Turn your head full right in a spacesuit and you're looking at the side of the helmet. But the SPS dome will give you a real large field of view," says Brand Griffin, Genesis' SPS program manager and AIAA Space Architecture Technical Committee member. He adds that a test dome has passed every impact test engineers could throw at it.

Inside the SPS, the occupant will breathe a normal mixture of oxygen and nitrogen — no need for the pure oxygen that today's astronauts breathe before venturing on EVAs to purge the body of nitrogen to prevent the bends.

In research and development right now are the safety-critical systems, including propulsion, autonomy, sensors and the spacecraft's robotic manipulators and tooling systems, Griffin says. And Genesis isn't taking risks with brand new tech: "I'd rather, especially for a critical system, use proven technology."

For instance, the SPS will be propelled by 24 nitrogen cold-gas thrusters, similar to those on NASA's strap-on Manned Maneuvering Unit in which astronaut Bruce McCandless propelled himself, untethered, 100 meters clear of space shuttle Challenger in February 1984. The SPS version is now being tested on a free-flying module lofted by an air table, Griffin says.

Also being derived from existing tech are the highly dexterous manipulators and tools that Orbital Reef engineers will need on EVAs. Genesis is developing these tools that will be robotically selected from a caddy on the SPS's "chest" in collaboration with California-based SRI International, which has previously pioneered precision surgical and bomb-defusing robot technologies. Prototypes have "all performed very, very well in tests, doing things you could never do in a spacesuit," says Griffin.

During all piloted and robotic tasks, the SPS must sense and avoid the inhabited, pressurized Orbital Reef. Its automation and sensor packs are now in trials in a simulator. Genesis hopes to have a robotic test system, with space-rated manipulators, ready to fly by mid-2025.

If successful, the SPS could fly way beyond low-Earth orbit."It would work at the Lunar Gateway or perhaps on a transit mission to Mars," Griffin says. "It has broad applications." ★

TABER MACCALLUM

POSITIONS: Since 2019, co-founder, co-CEO and chief technology officer of Space Perspective. Co-founder, chief technology officer and board member of World View Enterprises, 2012-2018. Co-founder and chief technology officer of Paragon Space Development Corp., 1993-2014. Analytical systems lead for Biosphere 2, 1984-1993.

NOTABLE: Holds multiple technology patents, including for a hazardous water diving suit for the U.S. Navy and the atmospheric monitoring system used in the Biosphere. At Paragon, he and Poynter led the 2014 StratEx project that launched then-Google executive Alan Eustace to an altitude of 41 kilometers via helium balloon for his record-breaking skydive. Explorers Club fellow since 1991.

AGE: 59

RESIDES: Cocoa Beach, Florida

EDUCATION: Left university to work for NASA on self-sustaining habitat experiments on the International Space Station.

SPACE PERSPECTIVE

JANE POYNTER

POSITIONS: Since 2019, co-founder, co-CEO and chief experience officer of Space Perspective. Co-founder, CEO and board member of World View Enterprises, 2012-2018. Co-founder and president of Paragon Space Development Corp., 1993-2014. Food production systems lead for Biosphere 2, 1984-1993.

NOTABLE: Besides co-founding multiple companies, she has authored two books and delivered a TED Talk on global sustainability that has been viewed over 1 million times. She also helped develop the first carbon credit rating program using mangroves in partnership with the United Nations and World Bank. Holds a patent for the world's first self-sustaining habitat used in multiple space programs. Explorers Club fellow since 1994.

AGE: 60

RESIDES: Cocoa Beach, Florida

EDUCATION: Left university to work for NASA on self-sustaining habitat experiments on the International Space Station.

Space balloon entrepreneurs

Married couple and tech visionaries Taber MacCallum and Jane Poynter are entering a critical period in their bid to create "the world's first luxury spaceflight experience." Customers would be lofted into the stratosphere inside a pressurized capsule with windows suspended from a hydrogen balloon providing views of the curvature of the Earth and the blackness of space. But first, MacCallum and Poynter must prove the safety of their design, and they plan to do that in 2023 through a series of uncrewed flight tests from Cape Canaveral in Florida, followed by a flight with a company crew and then the first customers in 2024. They are not alone in the market, having left World View Enterprises, another aspiring balloon company they founded in 2018, to create Space Perspective, for which they have raised $48 million. I reached them via video call in their Florida offices to discuss their confidence in stratospheric balloon tourism. Here is our conversation, compressed and lightly edited. — *Paul Brinkmann*

Q: Crowds gather to watch rocket launches, and people are paying millions to ride on them, so why do you believe tourists will pay for a long, slow balloon ride?

Jane Poynter: Taber and I have been working together for over 30 years on ways to make space accessible for as many people as possible. So yes, when we think of space travel, we normally think of high g's and training and special equipment like spacesuits. Very exciting, but not for everyone. So we developed this way of taking people above 99% of the atmosphere using a space balloon, which allows this incredibly gentle, comfortable, seamless experience.

> Sticklers might note that the 30-kilometer altitude is only one-third of the way to the Karman line, the international definition for the start of space. MacCallum and Poynter feel confident in the term "space" balloons because customers will see the Earth against the blackness of space and stars. — *PB*

We go up on the balloon and down on the balloon — very safe. It's also environmentally sustainable because it's an emissions-free vehicle. So when we talk to people, we are getting a hugely positive response. And since we've shown the design for our capsule's space lounge, people are just blown away because it completely changes our perception of what it means to go to space.

Taber MacCallum: We're also talking to people who want to do both, a rocket and a balloon. They liked the rocket ride, that was a cool experience, but the balloon would be something new and exciting. I get a lot of people who just don't want the rocket ride, but they want that quintessential astronaut experience of looking out the window in space. So it's an accessible alternative.

Q: Why do you want to work in stratospheric tourism like this, and why do it with a balloon?

MacCallum: When we talk with astronauts about some of the quintessential experiences they had and what they got out of it, it was really close to our experience in the Biosphere.

> He's referring to Biosphere 2, a greenhouse, habitat and research laboratory north of Tucson, Arizona, built in the late 1980s to demonstrate the viability of closed ecological systems to support and maintain human life in outer space. MacCallum and Poynter spent two years living in relative isolation inside the structure as part of an experiment. — *PB*

We had our world, which we could see, and it was three and a half acres. And when they're in space, they see our world, and you can see sort of the whole thing and understand how big it is and how small it is. And we think that is a really important and valuable experience for people to have. And so the question was, how do you make that experience accessible and not take two years living in a biosphere?

Poynter: On a personal level, and for the company, it's incredibly important that we behave like we are, in fact, crew members on this spaceship Earth. So our capsule, Spaceship Neptune, is essentially zero emissions, and we operate the company as a carbon-neutral company.

Q: Ticket sales opened last summer at $125,000 per seat, so how many have you sold, and what can you tell us about who's buying them?

Poynter: We've sold out our entire first year and most of our second year, so that is about 600 tickets and 80 flights. It's a broad demographic — people who are saving up to go and people who have bought two capsules, eight seats

"We go up attached to the balloon and back down attached to the balloon. So obviously, that eliminates all the complexities involved with dropping away from the balloon or transferring to another form of flight."

— Jane Poynter

> “I get a lot of people who just don’t want the rocket ride, but they want that quintessential astronaut experience of looking out the window in space. So it’s an accessible alternative.”
>
> **— Taber McCallum**

per capsule because they want to go with their friends, family or colleagues. About 40% of sales are buying out the entire capsule. Unlike some rocket trips that last only 10 minutes, this is a social experience lasting over six hours with a bar, restroom and music if wanted. We expect people to get married on some trips, for example. And we’ve arranged the seating such that it emphasizes both the incredible view but also the interaction among our explorers.

Q: You describe this as a gentler, more leisurely trip than on a rocket, but are there limitations on age or physical condition for passengers?

MacCallum: It’s a broad demographic that have bought tickets, but it turns out to be part of our licensing with the FAA that the issue of age is coming up. The first reaction from FAA is that you have to be 18 years old in order to sign the paperwork to do the flight. But then we said, “Well, you know, 16-year-olds can get a pilot’s license, and 14-year-olds can fly.” So we’re working with the FAA, and we’re trying to bring that age limit down. Lowering the age limit won’t be in the cards for a while, but we certainly would like to make it younger.

Poynter: With human spaceflight, we generally think about the compartment that holds the people at some point during the flight separating from its primary flight system. But we are able to have the entire flight without having to transfer to another system. We go up attached to the balloon and back down attached to the balloon. So obviously, that eliminates all the complexities involved with dropping away from the balloon or transferring to another form of flight. And that boosts our safety factor and makes this more accessible.

Q: Blue Origin is making a point of flying celebrities and expanding the age range of people who go to space, so how will you choose your first few crews?

Poynter: I don’t think we’ve decided yet who will be on our first flight, but we are really focused on making this broadly accessible. We’ll also be looking for people who can communicate about the experience in different ways — artists and musicians and leaders of all kinds, students, researchers. I mean, when William Shatner came back from his Blue Origin flight, he was very articulate about his experience, and that’s incredibly important.

▲ Space Perspective employees prepare a balloon and weighted test article for a June 2021 test flight near NASA’s Kennedy Space Center in Florida. The balloon and article stayed aloft for almost seven hours before splashing down in the Gulf of Mexico about 80 kilometers off Florida’s west coast.

Space Perspective

Q: You flew a weighted test article, not a capsule, suspended from a test balloon from Kennedy Space Center to about 30 kilometers and then a splashdown in the Gulf of Mexico last June. Where do things stand in testing and production now?

MacCallum: Yes, that test was very successful in terms of how we forecast the flight trajectory, how we manage the recovery ship and to go through the whole concept of operations. That success allowed us to dive into a big design and engineering cycle without having to run that test again. The capsule's interior design is a big part of that design cycle because we needed to lock down the configuration, ensuring we had the right size. Now we are engineering the capsule to the next level and run load analyses. We are in the process of building our first capsule, and we aim to reveal it later this year ahead of our test flight around the end of the year. We anticipate being in balloon and parachute production within a few months. So we'll see a lot of testing in 2023.

Q: As a balloon flight, there is no steering or navigation control, so why do you need a ninth person on board as a pilot?

MacCallum: You need somebody who's going to make sure that everyone feels comfortable. I think it's a bit unnerving not to have an expert there. Also there is a range of things that we'd like to have manual override on, just as a third or fourth level of safety — for example, with the life support system. When you go through the safety analysis, we've found a large benefit in having an expert on board, even just to ensure people are properly buckled in at the right times for example.

Q: I've read that your balloon is a standard design for stratospheric balloons, but tell me more about the hardware and the balloon materials.

MacCallum: It's a classic NASA balloon design: polyethylene filled with high-strength fibers to give it the tensile strength it needs. We're putting some formulation twists on it for added safety for human flight in a routine sense. Fundamentally, it's the same balloon that NASA has done 1,000-odd flights with for weather and other types of research. The person who leads our balloon team is Mitzi Giles, whose balloon designs hold records for mass above 100,000 feet. And she has made a huge number of NASA balloons. So we're really building on NASA's experience with balloons. We have a back-up parachute system, similar to

▲ Space Perspective's stratospheric balloons will travel about 19 kilometers per hour, a gentler ride than the one experienced on vehicles such as Blue Origin's New Shepard capsule. During the company's passenger flight in March, the capsule was accelerated to a top speed of 3,600 kph within minutes.

Blue Origin

parachutes you see bringing a capsule back for SpaceX or Blue Origin. The capsule is made of carbon fiber composite, and the capsule design team is led by Ryon Warren, who formerly worked as a contractor with Virgin Galactic.

Q: What will passengers experience during and after splashdown?

MacCallum: Our team of meteorologists will be forecasting where the splashdown will occur, the right time to begin the descent and the right rate of descent, so that is where our guidance, navigation and control will be. It's just not as complicated as the trajectory of a rocket. During the big test that we did in June, the ship was exactly where we wanted it, between half a kilometer and a kilometer away from the splashdown location, downwind. It was actually 800 meters or eight-tenths of a kilometer away from the splash location. Our recovery team is led by Ryan Nascimento, who developed splashdown recovery for SpaceX and did every recovery through their Inspiration4 splashdown in September. So he's the only person on the planet who has developed capsule recovery and actually done human capsule recovery since Apollo.

Poynter: This will be a truly bespoke experience, meaning it can be tailored to fit the customer expectations. For example, at the end of the flight, you can envision some people saying they've got to go, and we take them straight ashore and off they go. Other people might want to continue the incredible experience of our planet and get on a yacht and sail away or motor away. We're already having discussions about that.

Q: Since this is a hydrogen-filled balloon, how do you address questions about flammability, and do people ask you about the Hindenburg disaster?

MacCallum: Airships like the Hindenburg simply are not meant to have hydrogen as a lift gas. The Hindenburg was designed for helium and only had hydrogen because U.S. law at the time prevented sale of helium to Germany. That was 85 years ago in a vehicle that was not designed for hydrogen. Balloons are significantly different in that it's a single layer, so if any hydrogen leaks out, it just leaks into the air. There have been gas balloon flights dating back all the way to the 1700s, and there has never in the history of gas ballooning been an accident attributed to the use of hydrogen.

Poynter: It's also important to note that helium is nonrenewable, and it's in very scarce supply, so much so that the National Weather Service has moved to hydrogen for its balloons. And if you use helium, you're in competition with hospitals and the medical world, which uses helium in MRI machines. We're now seeing hydrogen increasingly used as a fuel. Sadly, the tragedy of the Hindenburg is seared in everyone's memory but frankly is completely irrelevant to what we're doing.

Q: How are you testing the capsule and balloon? Will you be testing to failure, exploding balloons, like Starship tests?

Poynter: No, we're not exploding balloons. We all love to watch that, but we don't need to do that.

MacCallum: I'm sure we'll have the odd hiccup and something that doesn't go right. That's why you're testing. But no big explosions. We'll have a very thorough uncrewed test program before we get into a crewed test program. And that's really where the rubber hits the road. You can do a lot in ground testing and materials testing, and we have an extraordinary materials testing lead to do just that. But in the end, it's got to be flight testing. You just can't simulate those environments on the ground.

Q: What will training be like for passengers?

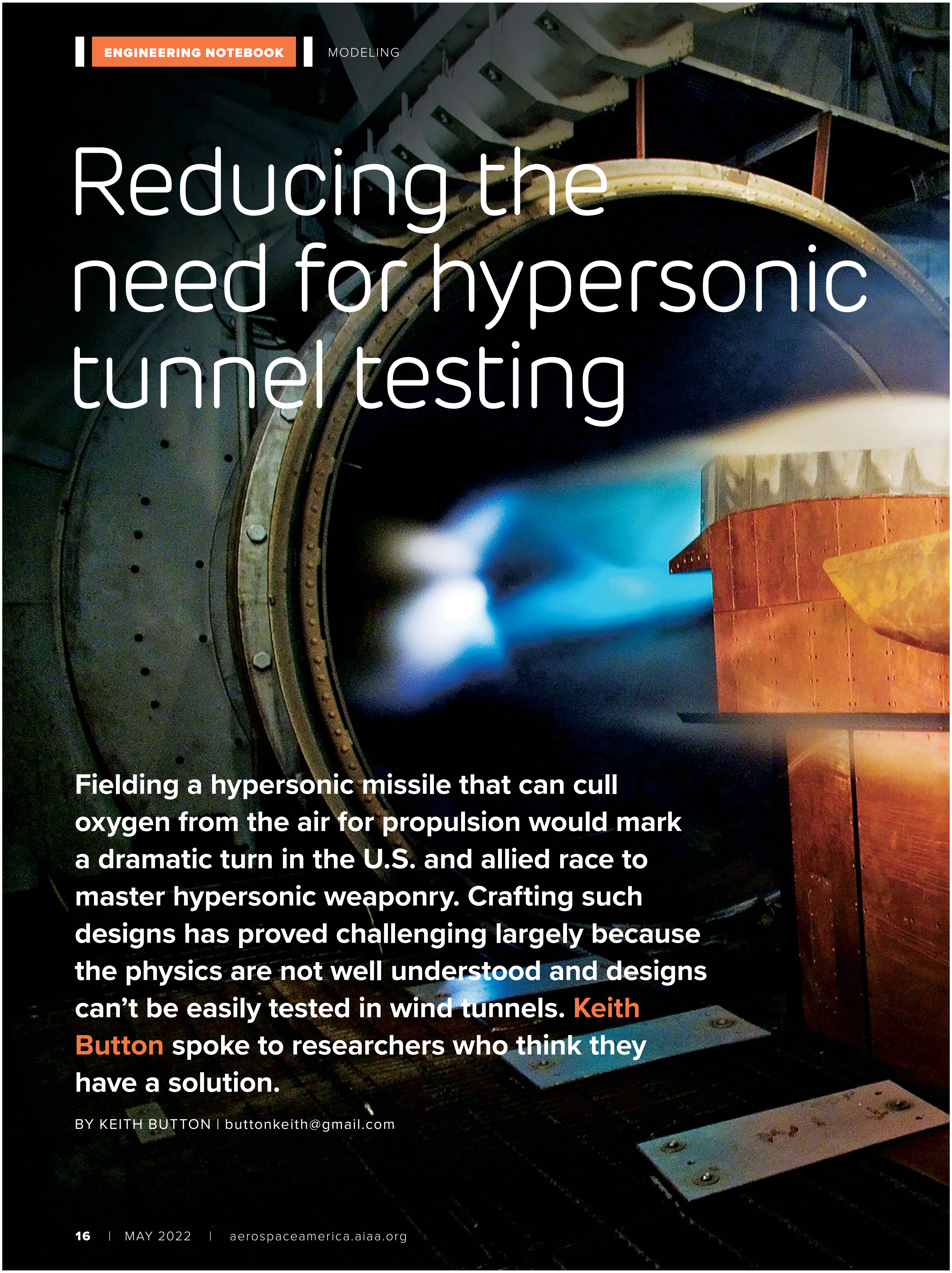
Poynter: It will be a little more than an airline flight. We'll be asking people to show up three days before their flight, partly due to weather prediction. We want to get people comfortable with the capsule, where everything is, how everything works. There will be a safety briefing to make sure they know how to be buckled into a seatbelt for the first 15 to 20 minutes and at the end of the flight also. Other than that, we want people to give us their drink menus.

Q: What's the biggest challenge Space Perspective is facing now?

MacCallum: The big challenge is getting to routine safe flight. You can do one-offs. We did the StratEx flight in 2014 when we were with Paragon, where we set the world record for human flight under a balloon, but doing flights routinely day in and day out — that means the system has to be absolutely as robust and simple as possible. So separating from the balloon, destroying the balloon, inflating a parachute, flying under a parachute, would add a huge amount of risk and complexity. So it was really Jane's idea to look at splashing down because, you know, you can't miss the ocean. ★

▲ Comfort was the driving force behind the design of the interior of the planned Spaceship Neptune capsule, shown here in a rendering. The reclining lounge chairs and walls of the cabin, which could seat up to eight, would be constructed of dark materials to reduce window glare.

Space Perspective



Reducing the need for hypersonic tunnel testing

Fielding a hypersonic missile that can cull oxygen from the air for propulsion would mark a dramatic turn in the U.S. and allied race to master hypersonic weaponry. Crafting such designs has proved challenging largely because the physics are not well understood and designs can't be easily tested in wind tunnels. Keith Button spoke to researchers who think they have a solution.

BY KEITH BUTTON | buttonkeith@gmail.com

Before flying its X-43 demonstrators, NASA tested full-scale models at speeds up to Mach 7 in the High-Temperature Tunnel at Langley Research Center in Virginia. One of the demonstrators reached a top speed of Mach 9.68 in November 2004 over the Pacific Ocean.

NASA

On its way to a target, an air-breathing hypersonic missile would need to plow through air of varying densities, temperatures and chemistries, compressing the air by forcing it into a narrow passage to provide oxygen for combustion. Scientists know from the brief experimental flights so far that the interactions with the air can result in strange phenomena. At about Mach 7, for instance, the bow shock from such a missile would begin to ignite the air in front of it, and by Mach 10, the air would be fully ignited.

Predicting how particular hypersonic designs will fare in such conditions has proved challenging, partly because of the limits of wind tunnel testing on physical models. Hypersonic flows can generally only be achieved for fractions of a second due to the huge tanks of air required, and even then, scientists have more than a need for speed. They need to know if control and combustion can be maintained in the thinner, colder, calmer air at high altitudes and in the thicker, warmer, more disturbed air at lower altitudes, for instance. The trouble is that some wind tunnels have particular strengths, and no single wind tunnel test anywhere can replicate all the characteristics of the medium. So successions of tests must be run.

"Whenever you check one box, another box gets unchecked," says hypersonics researcher Carlo Scalo, an associate professor of aeronautical and astronautical engineering at Purdue University in Indiana. The unchecked box requires a separate test, sometimes at a different facility.

These limits are one reason why air-breathing hypersonic missiles have yet to be fielded by China, Russia or the United States, despite the military value of speeding faster than traditional cruise missiles without having to initially fly to suborbital space, as boost-glide hypersonic missiles must.

Of special concern are the controllability of such a missile and the performance of the flow path. Firing up a supersonic combustion ramjet, or scramjet, and keeping the engine lit is like holding "a candle in a hurricane that's about 10 to 15 times faster than the fastest hurricane you can imagine," says Anand Veeraragavan, associate professor and co-director of the Centre for Hypersonics at the University of Queensland in Australia.

FACT

ALL-STAR TEAM For his "High Speed Reactive Flows" project, Venkat Raman, a professor of aerospace engineering at the University of Michigan, assembled experts from his university as well as Purdue University, Stanford University, the University of Illinois Urbana-Champaign, the University of Queensland in Australia and the University of Southern California.

The solution, a team of U.S. Navy-funded researchers say, could lie in developing a single computational model that accurately reflects key characteristics of the air flow, including its density, chemistry and temperature, so that performance of a scramjet design can be predicted. Such a model would reduce but never eliminate the need for wind tunnel testing.

"It's impossible to make a computational model that will perfectly represent reality," says Venkat Raman, a professor at the University of Michigan and the lead principal investigator for the project, "Discovering and Modeling Turbulence and Chemistry Interactions in High-Speed Reactive Flows."

Last year, Raman assembled a team of experts in modeling, molecular chemistry of combustion, scramjet engine design and hypersonic wind tunnel testing to pursue development of the computational model. In September, the team won a $7.5 million grant from the Office of Naval Research to pursue its development for five years ending in 2026.

Divide and conquer

The "one big model," as Scalo calls it, would need to be created from separate models focused on the specific characteristics of the hypersonic flow — the boxes that need to be checked, in Scalo's analogy.

An obvious challenge is that air flows externally around an air-breathing vehicle but also through it. Burning fuel in the engine creates chemical reactions between the hydrocarbon molecules in the fuel and the nitrogen and oxygen in the air, so detailed models of those reactions and their release of heat would need to be incorporated into the internal flow model. Meanwhile, modeling the external flow would have to account for a different set of chemical reactions: The high temperatures at hypersonic speeds can cause oxygen and nitrogen molecules in the air to break down or chemically react with the surface of the missile.

So the professors and their respective teams of post docs and graduate students split into three groups that will nevertheless coordinate closely: a group dedicated to the external flow, a group devoted to the internal flow and propulsion, and a group of mathematicians to help both the external and internal modelers.

"The groups of people that have been looking at these two flow paths have been developing over decades different expertise," says Scalo. "The goal of this grant is to bring them together."

By the end of the five-year project, which is one of the Multidisciplinary University Research Initiative grants that the U.S. military services award annually, the external and internal flow teams aim to have developed shared mathematical tools to build their models with, Scalo says.

As Raman explains, "in order to separate signal from noise — physics from just uncertainties in models and experiments — we need a mathematical framework. This is what the team is doing — using a novel mathematical framework to develop new tools and experiments that can probe the scramjet at extreme resolution."

The external engineering team has already received a boost from University of Southern California mathematicians, applying advanced mathematical tools to some of their simple external flow models to improve their accuracy, Scalo says.

"That's something that engineers cannot do without mathematicians," Scalo says. "Mathematicians have these magic tools to do that."

One of them is polynomial chaos expansion theory. Take, for example, any computational model that has a few "fudge factors" built in — variables that humans change the settings for based on their experience of what has produced the best results in the past. The polynomial chaos expansion theory tool can change the settings for hundreds of such fudge factors at the same time and provide a prediction of the best setting, or predict how much each of the fudge factors might influence the model's outcome, Scalo says.

To build a computational model for the exterior flow, the professors have further divided the task: Raman's Michigan team is creating a general model that can encompass the entire surface of a missile, while Scalo's Purdue team is making one to home in on a napkin-sized piece of the surface. The detailed model, focusing on air flow within 2 millimeters of the surface of the missile, divides the space into a grid of calculations for cubes that are 10 or 20 microns wide. The grid — also known as a mesh — for the general model will calculate for cubes that are 100 to 1,000 times larger, with pockets of finer grids embedded within it.

"He gets the whole solution, but not very accurately; I get a very accurate solution, but of a small portion of the flow," Scalo says. The two teams intend to merge their computational models.

Accounting for shockwaves

For both the external and internal flow teams, their computational models will have to account for shockwaves that form when a component of a vehicle, such as the engine inlet on a missile, pushes through the air at hypersonic speeds. Shockwaves introduce sharp changes to air pressure, density and temperature, which are all critical in determining aerodynamic characteristics such as lift and drag. Plus, shockwaves can cause turbulence and other sudden changes in the direction of flow, which can affect the stability of combustion in an engine or how well a missile flies.

Unlike subsonic air flows — the realm of most conventional aerodynamic models — at hypersonic speeds the air can be highly compressible and squishy.

An artist's rendering of Lockheed Martin's Hypersonic Air-breathing Weapon Concept demonstrator. DARPA has a similar contract with Raytheon Technologies for another version.

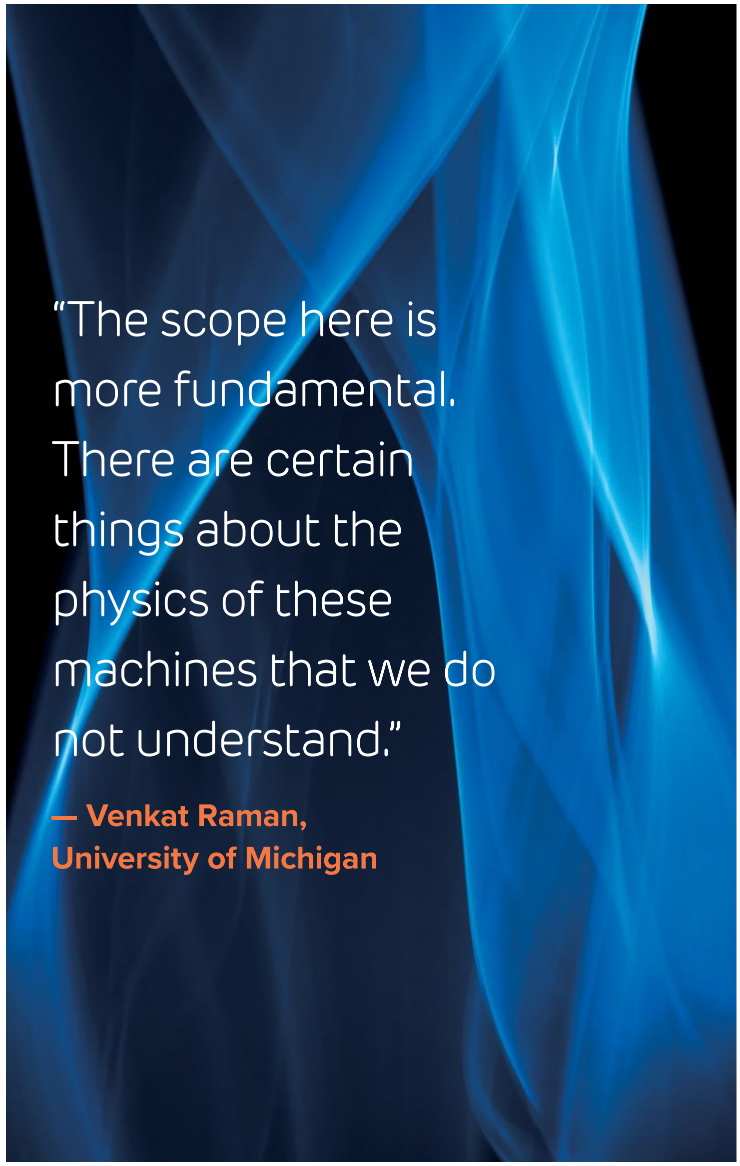
Lockheed Martin Aeronautics

The U.S. Air Force's X-51A Waverider previously held the record for longest air-breathing hypersonic flight. Once released from the wing of a B-52 Stratofortress, the demonstrator's scramjet engine lit and accelerated the aircraft for 210 seconds during the final test flight of the program in May 2013.

U.S. Air Force/Bobbi Zapka

Record-setting flight

In March, a Hypersonic Air-breathing Weapon Concept missile powered by an air-breathing supersonic combustion ramjet, or scramjet, "set the U.S. record for scramjet endurance," DARPA director Stefanie Tompkins told a U.S. Senate Armed Services subcommittee. The missile was the Lockheed Martin version of the HAWC, and it was dropped from a carrier aircraft and boosted by rocket to the scramjet speed envelope. The scramjet then lit and accelerated the missile at hypersonic speeds, according to DARPA. The duration of the scramjet portion of the flight and the top speed were not specified, but DARPA said the missile flew under scramjet power for longer than 210 seconds, the record held by the U.S. Air Force's X-51A. — *Keith Button*



So when the air temporarily slams to a halt at the surface of an object in the flow path, the air upstream from the object squishes down into a thicker substance and a shock develops, with air pressure jumping as much as 10 times higher, depending on the velocity.

The high temperatures created by hypersonic air flows also change the aerodynamics. At between Mach 5 and Mach 10, the air is heated to up to 2,700 degrees Celsius — so hot that the skin of hypersonic missiles must be made of a ceramic or ablative material because a metal exterior would melt. Above Mach 10, as temperatures exceed 3,700 degrees Celsius, the air is set on fire even before it touches the missile, and then other chemical reactions are set off when it does touch the surface. The combination of heat and pressure causes oxygen and nitrogen molecules in the atmosphere to break apart, creating their own fuel-oxidizing mixture.

Before the current five-year modeling project, Scalo had developed aerodynamic models for low hypersonic speeds based on supersonic models. Under the current grant, he is expanding the models into higher velocities at which the heat and pressure extremes create chemical reactions that alter the aerodynamics.

Bullet launch

In Australia, a close ally of the United States, Scalo will put his computational models to the test at one of the wind tunnels in Queensland. He'll focus specifically on high-density flows that would ignite in front of a vehicle, conditions that the Queensland tunnel can replicate.

"Great, that checks a box that cannot be checked at Purdue," he says, referring to his university's tunnel that is not involved in the project but is known for its exceptionally smooth flow replicating calm air at higher altitudes. He'll compare his model's aerodynamic predictions against tests of a physical model and then adjust the computational models based on the test results.

For each of those tests, a tank of high-pressure air will provide the propulsion to launch a 90-kilogram piston down a long tube, like a bullet through the barrel of a gun, compressing air in front of it until a metal disk 1 to 2 millimeters thick ruptures, with the thickness determining the size of the shockwave caused by the rupture. The rupture will push air through a nozzle into a 10-meter-long shock tube containing the mock vehicle shape, over which the hypersonic air flows for a split second. With readings from pressure sensors affixed to surfaces in the shock tube, the Queensland team can calculate the velocity and temperatures created during the test.

Scalo plans to begin adding simple chemistry models to his computer model and then progressively more complicated chemistry models until his computer model fully matches the wind tunnel tests. Then he'll consult with the internal flow engineering team to check his modeling of chemical reactions against theirs.

"The bet is that we will be able to find the same type of physics — the interaction between flow and chemistry," he says.

For the internal flow team, one of the main tasks is to build a combustion chemistry model. If the combustion chemistry model is wrong, for example, then the predictions by the larger computational model for the internal flow about how easily the scramjet engine will fire up will be inaccurate. To improve the accuracy of potential chemistry models of hypersonic engines, part of the team is checking the models against 1,400 sets of data created by tests dating back to the 1920s, says Hai Wang, professor of mechanical engineering at Stanford University.

The professors need to incorporate data from a wide range of these previous experiments into their combustion chemistry model to account for a wide range of conditions in a scramjet engine, including shockwaves that create air pressure ranges from normal at sea level to 100 times greater than normal, Wang says. These tests include shock tube experiments with lower than hypersonic flows but which created sudden air pressure changes that heated gas up to combustion almost instantaneously.

Inside a scramjet engine, there are intentionally designed cavities that slow the air so that it can be ignited and areas where the air will momentarily stop, which dramatically increases its temperature, says Tonghun Lee, professor of mechanical science and engineering at the University of Illinois Urbana-Champaign. For instance, the temperature of air that was traveling at Mach 5 can suddenly rise to 1,000 degrees Celsius.

As a starting point for modeling this internal flow phenomena, Lee turned to gas turbine engine models, which will be tested in hypersonic conditions to see how their predictions hold up. But those turbine engine models have been meticulously designed and tweaked for maximum accuracy for a very specific range of temperature and pressure and for a predictable set of circumstances: Air comes in, it compresses to a high pressure, and then fuel is added and ignites. The hypersonic model has to make predictions over a much wider range.

To make sure a model can do that, plans call for running hypersonic air flows through mock engines at Illinois Urbana-Champaign wind tunnels. Windows in the mock engine ducts will expose the flow path to sensors to record the chemical reactions, molecular states of air and fuel, temperatures and velocities at every point in the flow path, says Lee, who will head up the wind tunnel testing. High-speed cameras capable of shooting 100,000 frames per second will record images as lasers scatter light off titanium oxide particles added to the flow stream for particle image velocimetry. As successive images of the 40-nanometer-diameter particles are recorded during the test, their velocity will be calculated from their movement.

If things go as Raman hopes, the impact of the project will be bigger than any particular application.

“The scope here is more fundamental. There are certain things about the physics of these machines that we do not understand,” he says. ★

Editor-in-chief Ben Iannotta contributed to this report.

CHALLENGING TIMES UNIQUE OPPORTUNITIES

There's no shortage of challenges facing the aviation industry: the supply chain is at a pivotal point, there is a downturn in demand, environmental sustainability is critical, and experts warn of a growing talent shortage. At this inflection point, how do we turn setbacks into comebacks? We have the opportunity to reset expectations, redefine roles, and accelerate change. Join us as we set the stage for the future and explore the next golden age of aviation.

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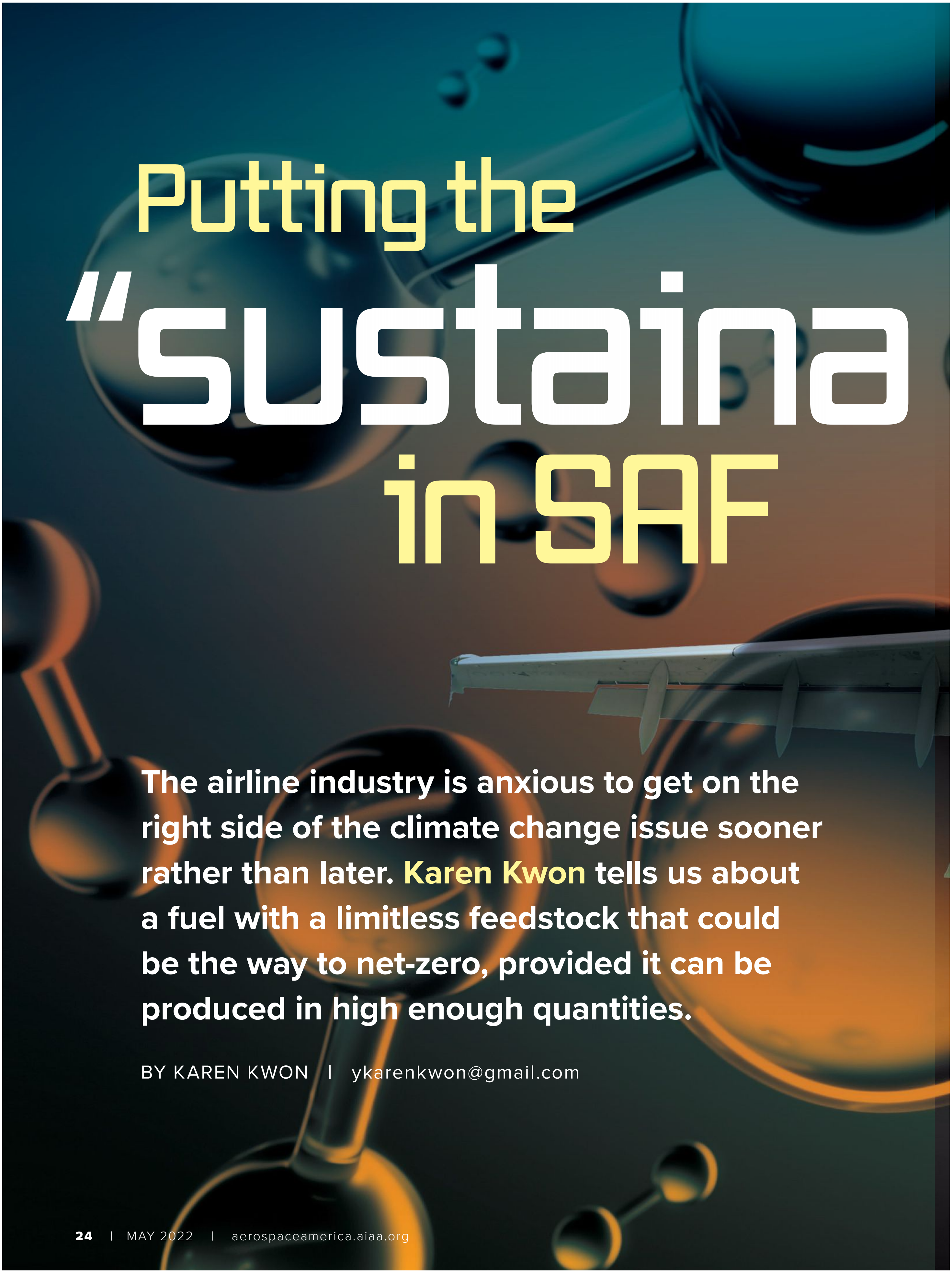


Putting the "sustaina in SAF

The airline industry is anxious to get on the right side of the climate change issue sooner rather than later. Karen Kwon tells us about a fuel with a limitless feedstock that could be the way to net-zero, provided it can be produced in high enough quantities.

BY KAREN KWON | ykarenkwon@gmail.com


ble”

▲ In step two of Prometheus' jet fuel production process, carbon and hydrogen atoms captured from the air run over a carbon dioxide electrolyzer, an older version of which is shown here during 2021 tests in California. The electrolyzer catalyzes a reaction in which the carbon molecules combine with hydrogen from the water to create alcohol that would later be refined into jet fuel.

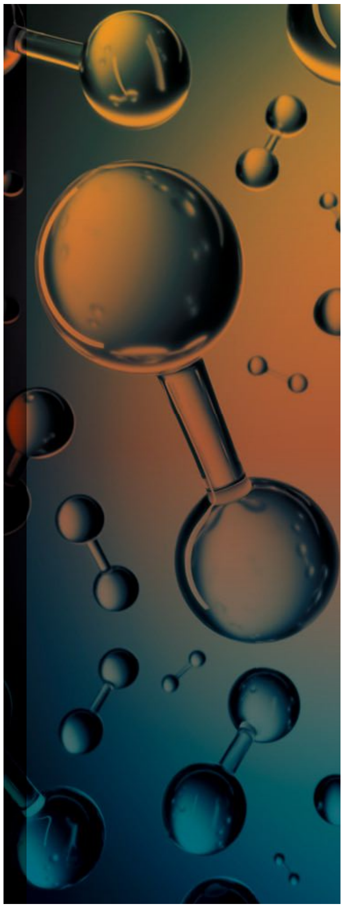
Prometheus Fuels

On a Sunday in February 2008, a Virgin Atlantic Boeing 747 with two pilots and some technicians took off from London bound for Amsterdam for a history-making test flight. One of the jet's four engines burned a mix of 80% conventional fuel and 20% fuel derived from coconut and babassu palm seed oil, making Virgin the first airline to fly a jet at least partially on biofuel.

"This pioneering flight will enable those of us who are serious about reducing our carbon emissions to go on developing the fuels of the future, fuels which will power our aircraft in the years ahead," proclaimed Richard Branson, the founder of Virgin Group, in a press release at the time.

Just as Branson predicted, various classes of alternative jet fuels have been introduced in the years since, most lately in the name of meeting a goal of achieving net-zero carbon emissions by 2050. On the one hand, commercial aviation accounts for just a few percent of global carbon emissions — 2.4% as of 2018. On the other hand, if those emissions came from a country, that percentage would place the country sixth in terms of highest carbon dioxide emissions, between Japan and Germany. Also in the years since 2008, the industry adopted the term "sustainable aviation fuel," or SAF, to capture the idea of fuels produced from a variety of possible feedstocks whose production won't deplete natural resources.

First to catch on were the biofuels, and then came fuels derived from waste including municipal garbage, used cooking oils and discarded animal fats. Now, a fierce competition is playing out to be first to affordably mass produce the next class of SAFs, and one that



"It turns out being able to integrate all of the engineering from air capture to fuel delivery allows you to be very low cost."

— Rob McGinnis, Prometheus

arguably could be the most environmentally friendly yet. Carbon dioxide would be culled from the air in massive volumes, mixed with water, and this brew would be electrified to create hydrocarbons.

The plans of two rivals in the field are emblematic of the contrasting strategies and the drama ahead as they and a handful of others race to meet a goal of making electrofuel SAFs widely available to airlines, possibly by 2025. One of the companies is Johnson Matthey, a multinational chemicals and sustainable technologies firm headquartered in England with 14,000 employees that licenses key technologies to SAF producers. Another is Prometheus Fuels, a California startup of about 30 employees. In 2019, investors such as Maersk and BMW valued Prometheus at $1.5 billion, making it the world's first electrofuels company to be valued at over a billion dollars.

Johnson Matthey and Prometheus share the goal of contributing to, and perhaps even dominating, the airline industry's effort to become carbon neutral by 2050, and doing so without creating new societal or environmental negatives. Like all SAFs, the electrofuels must be similar enough, chemically speaking, to conventional jet fuels that they could someday replace today's Jet A and Jet A-1 fuels without any engine modifications. Current regulations don't allow a plane to fly solely on such "drop-in" SAFs of any form. The fuels must be mixed in with the conventional kind to a maximum blend of 50/50.

This cautious rollout ensures that "airplanes [burning SAFs] don't start falling out of the sky all of a sudden," says Martin Junginger, a professor of bio-based economy at Utrecht University in the Netherlands. However, that fact also means that engines

▲ A technician pumps sustainable aviation fuel derived from crop residue and animal fats into a Boeing 737 MAX 8 at O'Hare International Airport in Chicago last December. The passenger flight to Washington, D.C., was United Airlines' first with one engine powered by 100% SAF.

United Airlines

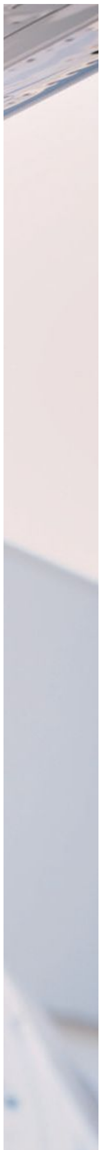
powered by SAFs emit almost exactly the same amount of carbon dioxide as those burning conventional fuels, though preliminary research shows that SAF may produce less soot than conventional fuels, yielding less environmental harm at high altitudes.

So how can any SAF, electrofuel or otherwise, bear the "sustainable" moniker? In the case of an electrofuel, no more carbon dioxide would be released during combustion than was culled from the atmosphere, although combustion is not the only place the carbon question arises. In the case of a biofuel, such as the one demonstrated by Virgin, the emissions from the aircraft would be offset by the fact that new fuel crops are continually growing, and as they do they extract carbon dioxide from the air to create the carbon compounds that form their stems, leaves and fruit. The International Civil Aviation Organization, the United Nations agency that sets guidelines for deciding whether a fuel should be considered a SAF, considers such sequestration of carbon a "negative" in the mathematical sense of sequestration subtracting carbon from the atmosphere. Another example of a negative would be the amount of methane gas averted when municipal garbage is turned into SAF, rather than being allowed to rot in a landfill.

The ideal sum in each case would be a self-sustaining cycle that does not add carbon dioxide to the atmosphere. However, one big proviso looms. ICAO assesses the entire carbon footprint of SAF production, meaning the complete life cycle spanning from the fuel's origins as a feedstock to its processing and transport. Just how sustainable a SAF truly is depends on how much fossil fuel, if any, was burned to power the tractor that plowed the fields or the equipment that harvested or processed and transported the feedstock.

Looking through that lens, "not everything is sustainable; there's actually quite a lot of variation," says Nikita Pavlenko, fuels program lead for the International Council on Clean Transportation, a Washington, D.C.-based nonprofit research group.

Prometheus thinks it has an edge here. By taking



◀ Pratt and Whitney is among the engine manufacturers conducting ground tests with 100% sustainable aviation fuel to verify their engine designs perform comparably on these alternative fuels. In March, engineers at the company's West Palm Beach facility used a SAF derived from vegetable oil to power one of the new GTF Advantage engines, scheduled to enter service in 2024 on Airbus A320neo aircraft.

Pratt and Whitney

charge of the entire process, from capturing carbon dioxide from the air to creating the SAF in a multistep process, the company plans to make sure the energy for each step comes from renewable sources such as solar panels. And the company sees another benefit:

"It turns out being able to integrate all of the engineering from air capture to fuel delivery allows you to be very low cost," says Rob McGinnis, founder and CEO of the company.

With a commercial-scale prototype in hand, the company announced a deal with American Airlines last July in which American would purchase up to 10 million gallons (38 million liters) of SAF from Prometheus by 2025.

Johnson Matthey, in contrast, leaves the carbon dioxide capture to others and is focusing on the chemical conversion aspect. Deciding what constitutes environmentally friendly should be up to legislation passed by governments around the world, says Paul Ticehurst, who develops new business opportunities for the company, adding, "we take sustainability really seriously."

So how do their respective technologies work? There is more than one way to make jet fuel from carbon dioxide, but all involve electrolysis, in which electricity flows between a cathode and anode in a container of some kind and provides electrons to water molecules to produce oxygen and hydrogen gases. This is where the "electro" part comes from in the name electrofuel, and why this fuel-making process is often called "power-to-liquid."

Beyond that, the plans of Johnson Matthey and Prometheus differ markedly. Prometheus plans to expand from its prototype to build shipping-container-sized devices it calls Titan Fuel Forges. Just as with the prototype, air will be sucked into each device, where water will absorb carbon dioxide gas. Electrolysis then breaks down the water, with the resulting hydrogen combining with the carbon dioxide to form bicarbonate that will be converted to alcohol. This synthesized alcohol will be transformed into SAF through a process called alcohol-to-jet. The company

“The problem is that we have to basically eat french fries for probably 10 years in order to be able to fly short distance.”

— **Martin Junginger, Utrecht University**

plans to apply the same overall technology to produce gasoline and diesel as well.

In another difference, Johnson Matthey avoids the alcohol step. Hydrogen gas combines with carbon dioxide to create carbon monoxide, which then combines with more hydrogen to produce synthesis gas, or syngas. Syngas will be further processed via a chemical process called Fischer–Tropsch into synthetic crude oil, which will then be transformed into diesel, gasoline and SAF.

No matter whose strategy turns out to be best, backers of electrofuels see an additional environmental and social advantage to their products that has nothing to do with carbon. Between 2009 and 2011, auto fuel-makers received backlash as production of bioethanol, such as corn ethanol, caused food prices to spike in some locales. That experience made the aviation industry “extremely reluctant in using any vegetable- or food-crop-based fuels,” says the Utrecht professor Junginger.

Cost, not surprisingly, was also an issue.

“When you’re growing a crop, you need a lot of land, you need a lot of sunlight, you need a lot of fertilizer, you need a lot of water,” says Aaron Robinson, senior manager of environmental strategy and sustainability at United Airlines, “which ultimately makes it rather expensive to go and produce it.”

At least for the near term, the airlines are showing more interest in SAFs made from waste. In December, for example, a United Airlines Boeing 737 MAX 8 took off from Chicago on a regularly scheduled flight to Washington, D.C., becoming the first passenger jet to fly on 100% SAF in one of its two engines. The SAF was made from cooking oil and discarded animal fats.

“The great thing about waste is it’s relatively affordable to procure because no one really wants it or has another good use for it,” says Robinson.

At the same time, Robinson thinks that the industry will eventually have to shift away from concocting SAFs this way as society moves toward reducing waste and more people look to travel by air.

“Ultimately, there’s not going to be enough waste to be able to source to produce [fuels] for all the needs,” he says.

Here’s how Junginger sums it up: “The problem is that we have to basically eat french fries for probably 10 years in order to be able to fly short distance.”

Because of its size, electrofuel-maker Johnson Matthey says it’s especially well positioned to meet the growing demand for jet fuel.

“We think that it’s important that the big companies are involved in [the electrofuel production], not just the small developers, because we can get to that scale that’s required so much quicker,” Ticehurst says.

As for where matters stand, the competitive development of electrofuels is playing out against a backdrop of research toward hydrogen-powered aircraft by Airbus and research into radical new aircraft designs that move away from tubes with wings.

The electrofuel companies are well aware of this, but Ticehurst says time is on their side.

“We’re saying sustainable aviation fuel is key because it’s something that can be done today.” ★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SEEKING CERTIFICATION

Joby Aviation is working with FAA to get its electric aircraft design certified in 2023 so that the company can begin ferrying passengers around major U.S. cities in 2024. Can the advanced air mobility company cross the finish line? Aaron Karp set out to find the answer.

BY AARON KARP | aaronkarp74@gmail.com

APPROVED?

Outside of public view, air taxi developer Joby Aviation began flying the first full-scale prototype of its four-passenger, piloted electric rotorcraft in 2017. Representatives from FAA were on-site in California to view the initial flights.

Santa Cruz-based Joby may not have been ready for the public to see the first version of its 2,177-kilogram S4, the six-propeller, battery-powered aircraft that company executives believe will ferry passengers around multiple major cities this decade. Yet, it was critical for FAA to be involved given that there is no future for Joby without receiving a type certificate from the agency verifying that its electric vertical takeoff and landing aircraft, or eVTOL, design complies with airworthiness standards. This is one of three certifications FAA must grant before Joby can begin producing S4s in large quantities and flying passengers.

As Joby appears closest of the eVTOL developers to achieving type certification, the company's progress is being watched closely by other developers, traditional aerospace manufacturers, officials in large metropolitan areas where eVTOLs could operate, aviation regulators around the world and others. Certification could prove to be a turning point for the emerging industry and potentially pave the way for the other half-dozen or so well-funded air taxi developers seeking to gain regulatory approval for their passenger eVTOLs. But missing FAA's marks could lead to skepticism about this entire future class of small electric aircraft.

▲ Joby Aviation completed about 1,000 flights with this pre-production prototype of its electric vertical takeoff and landing design before the aircraft crashed with no one aboard in February.

Joby Aviation

"Joby has made the most progress so far among eVTOL developers toward certification," Edison Yu, an analyst with Deutsche Bank who covers the eVTOL sector, told me in an interview. Yu authored a 48-page report, "Electrifying the sky," released by Deutsche Bank in April, analyzing the efforts of Joby and two of its primary competitors, Archer Aviation of Palo Alto in California and Vertical Aerospace of Bristol in the U.K., to bring eVTOLs to market.

Yu believes those three companies are best positioned to achieve certification of a piloted, passenger eVTOL within the next two to three years, with Joby in the lead. This ranking differs slightly from that of the Advanced Air Mobility Reality Index that SMG Consulting of Arizona publishes monthly, though certification is just one factor in SMG's ranking. The latest iteration puts Joby in first, Archer in sixth place and Vertical in 11th.

Yu says Joby earned the top spot in his report because it has "the highest performing aircraft across nearly all metrics" with "the best raw specs." Joby says the S4 will operate up to distances of 240 kilometers and at speeds of up to 320 kph.

Another box the company has checked, according to Yu, is securing adequate funding — specifically $394 million from Toyota and $125 million from Uber, whose Elevate research and development division became part of Joby in 2020. Uber plans to incorporate Joby's air taxis into its ride-sharing app. Also, last August, Joby raised upward of $1 billion in an initial public offering on the New York Stock Exchange.

"Getting an aircraft through certification and into mass production will cost at least $500 million," Yu says.

Joby, Archer and Vertical are relying on a similar concept for their aircraft designs: The eVTOLs would lift off with propellers, and then those propellers would be tilted for cruise. Yu says this is the best way to optimize performance but cautions the trade-off "is higher technological complexity," which could make certification more complicated.

Existing regulations

A year after FAA officials witnessed the first flights of the S4 in 2017, the agency made a decision that greatly enhanced Joby's prospects for getting the aircraft certified. FAA published a notice in the Federal Register that it would certify eVTOLs under existing regulations, rather than develop new standards. The aircraft would fit into FAA's Part 23 airworthiness category used for small airplanes carrying fewer than 15 passengers, the agency said.

For novel technologies on eVTOLs, FAA said it would apply "special conditions" — but these will not require a certification process that substantially deviates from processes for certifying traditional airplanes and helicopters.

"Some [eVTOL] certifications could require the FAA to issue special conditions or additional airworthiness criteria, depending on the type of project," FAA said in a written statement in response to my queries about Joby's certification. "With regards to policies and procedures, the FAA's current regulations allow aircraft to meet our strict safety standards in innovative ways," the statement said in an apparent reference to the 2016 rewriting of Part 23 that made the regulations less prescriptive in the name of permitting the rapid modernization of general aviation

"IT'S KIND OF LIKE A SERIES OF LEGO BLOCKS LEADING TO THE FINAL AIRCRAFT. THE CERTIFICATION TESTING PROCESS REQUIRES YOU TO GO THROUGH ALL THESE LAYERS TO MAKE SURE EVERYTHING BOTTOM UP IS COMPLIANT WITH THE RULES."

— Didier Papadopoulos, Joby Aviation

designs. "We use the same data-driven approach when evaluating these complex systems that has created the safest aviation system in the world. We apply this methodical, process-oriented, safety-first approach to all aircraft."

The flexibility inherent in Part 23 has paved the way for Joby's potential certification of the S4, the company's executives say.

"It lets us work in a modern certification path using standards and test procedures that are known quantities," Greg Bowles, a former vice president for innovation at the Washington, D.C., and Brussels-based General Aviation Manufacturers Association and now Joby's head of government affairs. "The core of our certification follows a methodology of various aerospace products previously certified."

That's a different approach than the one being taken by the European Union Aviation Safety Agency, EASA, which has declared all forms of VTOLs a new kind of aircraft for certification purposes. In an explanation on its website, EASA cites "the absence of suitable certification specifications" for eVTOLs for its decision, adding it has "developed a complete set of dedicated technical specifications," released in 2019, providing a broad framework for how eVTOLs will be certified.

According to EASA, the agency "is now in the process of creating new rules and revising existing ones to address new technologies, operational air transport concepts, flight crew and operator licensing requirements" related to eVTOLs.

Traditionally, developers have gotten their aircraft initially certified in the market where they are based, with the intent of getting that certification recognized by other major aviation authorities around the world. But EASA's designation of eVTOLs as novel could make it challenging for Vertical and other eVTOL developers that aim to operate their aircraft in European cities by the middle of this decade, such as Volocopter of Germany. Vertical plans to get its eVTOL certified first by the U.K. Civil Aviation Authority, but this would not be automatically accepted by EASA, as was the case before the U.K. left the European Union, and could limit the potential markets in which the aircraft can operate.

Vertical, which aims to sell its aircraft to airlines and other operators (as opposed to Joby, which plans to operate its own aircraft), has said it needs EASA's signoff after CAA's. It will therefore attempt to adhere to EASA standards during its U.K. certification.

The situation also makes it more difficult for Joby's aircraft, if certified by FAA, to be recognized as certified by EASA. The two agencies usually largely accept the other's judgment regarding aircraft certifications, alleviating the need for aircraft manufacturers to go through separate, lengthy certification programs.

"There's a lot of work to be done" to get EASA to recognize FAA's potential certification of the S4, Bowles concedes.

But he adds: "Below the surface of [EASA's] decision, they're actually reusing the same methods of compliance [previously used for other aircraft] for the most part." This means "the technical details are not that far off, but the approach of setting these vehicles aside in Europe as special is what's unique. We'll keep watching as that evolves."

And there are signs that FAA might be open to accepting other agencies' certifications. FAA in early

▲ Among the many certification tasks will be to verify that the carbon fiber composite that comprises the S4 airframe meets FAA standards for characteristics including strength.

Joby Aviation

March issued a statement that officials were "engaged in a range of bilateral and multilateral discussions " with counterparts at CAA "focused on facilitating certification and validating new eVTOL aircraft."

Separately from that evolution, there is a bonus for Joby regarding the S4 being classified under Part 23: Since FAA is using existing regulations, pilots can seamlessly move from operating other types of commercial aircraft to flying eVTOLs. Those pilots will just need to undergo model-specific training, rather than starting from scratch to get licensed to operate a completely new category of aircraft. Joby aims to begin commercial operations in at least one U.S. city nearly immediately after gaining certification, so ready-made pilots are necessary.

Preparing for certification

Joby aims to complete the S4 certification by the end of next year. The company is already well into the process, having first engaged FAA in 2015 — two years before those initial flights with a full-scale prototype.

And executives are not overly concerned about the special conditions FAA will apply to the S4.

"Just because there's a special condition, it doesn't mean it's something bad," says Didier Papadopoulos, Joby's engineer leading S4 certification. "It just recognizes the fact that existing rules don't apply" to particular technologies on the aircraft.

"The good news about that is for the most part, all the special conditions apply to technologies we are developing in-house, so the know-how is here."

Bowles says Joby has "baked in" extensive testing to meet special conditions into its certification timeline.

Joby sees this vertical integration of production as a differentiating strength among its competitors. Joby has been experimenting with the idea of an electrified air taxi since it was founded in 2009. When the concept was in its infancy, Joby started developing its own technologies — a practice it continues today — giving the company independence from the numerous suppliers on which most aircraft programs depend.

Joby sees two advantages to this approach: First, a disruption at a supplier will not delay the certification process. Second, and perhaps more importantly, if FAA spots a problem with a system, there will be no middleman. Joby can make the fix without depending on the engineering of another company.

"That is so critical in my mind, rather than having dependency on third-party suppliers or suboptimal designs that were really designed for broader applications and not just for this aircraft," Papadopoulos says. "Whenever we need to make changes, it's phenomenal how quickly we can do it."

A big watch item for FAA, which analyst Yu says will certainly come under a special condition, is the four battery packs arrayed under the S4's wing. He predicts that the battery packs could create weight imbalance issues that would force Joby to compromise by reducing the number of passenger seats from four to three. But Yu doesn't think that would be a deal breaker, because Joby is targeting an average passenger load factor of 2.3.

Agreeing on process

There are three key thresholds that Joby must clear to gain type certification for the S4, one of which it crossed last year and the next it aims to complete this year, leaving 2023 to gain final type certification.

Joby last year received from FAA the "G-1 Certification Basis," a document spelling out the agreed upon airworthiness and environmental requirements for the aircraft. FAA and Joby are now 70% through creating the follow-up "G-2" compliance checklist specifying how Joby will demonstrate through certification flights that that S4 meets those requirements. The list is scheduled to be ready by midyear, Joby says.

Joby is in contact with FAA on "multiple fronts," Papadopoulos says. "We have regular sync ups with them on everything from the certification [process] to the types of testing we're going to do. We're doing all formats of meetings, from Zoom to on-site visits by FAA."

Once FAA signs off on the G-2, Joby can begin certification flight testing. While another version of the S4 — which Joby calls a "pre-production prototype" — clocked approximately 1,000 flights since its first flight in 2019, none of those counted toward certification. The data collected was quite valuable, but only a flight testing aircraft with the exact specifications Joby plans to bring to market can make formal certification flights.

That pre-production prototype crashed in February during a remotely piloted test flight near Monterey in California in which Joby was aggressively pushing the aircraft's flight envelope. No one was injured, but the aircraft was "substantially damaged," according to the report issued by the U.S. National Transportation Safety Board. A second pre-production S4 was rolled out in January and resumed flight testing in March. Joby maintains that the crash does not affect its certification timeline.

For safety, some flights of the current iteration of the S4 are conducted by remote control without a pilot aboard, such as when Joby wants to push the envelope, though that will be done cautiously. Papadopoulos says the ongoing flights with the second aircraft will not push the boundaries like the prior S4 did. The current flight tests focus "more toward lower speeds and takeoff and landing," he explains. The next aircraft to be built, he says, will be mostly used for testing flight systems.

"We're going to develop as many aircraft as we need" to achieve certification, he adds.

When those certification test flights commence, they will have to be piloted since that is how the aircraft will go to market. Joby has highly automated the flight controls, which company executives say will make it quite possible to transition to a remotely piloted eVTOL in the future.

Meanwhile, Joby does not have to wait for flight testing to begin the process of gaining FAA approval for smaller S4 parts and systems being refined in Joby's design laboratory.

"You need to think about the aircraft as a sort of a pyramid with building blocks," Papadopoulos says. "At the bottom end are the smallest components. As we move up, you're starting to talk about larger components like a piece of equipment or a piece of electronics. And then as you move up, you're talking about subsystems and systems and then the aircraft. It's kind of like a series of Lego blocks leading to the final aircraft. The certification testing process requires you to go through all these layers to make sure everything bottom-up is compliant with the rules."

In this case, a lot more than Joby's success as an individual company could hinge on that compliance. ★

▲ Volocopter of Germany plans to obtain European certification for its two-seat VoloCity air taxi design before seeking FAA certification to operate in the U.S. The company completed the first flight with its pre-production VoloCity in December.

Volocopter

ANALYSIS | SPACE LAUNCH

Bending the cost curve

SpaceX's breakthroughs in reusability sprang from the lessons of history. The coming Starship space launch attempt portends an even more profound lowering of launch costs in the years ahead. Phil Moynihan and Eugene Ustinov share their analysis.

BY PHILIP MOYNIHAN AND EUGENE USTINOV

The desire for low-cost access to space has been the dream of all spacefaring nations since the launch of Sputnik I in 1957. It's that brass ring that everyone reaches for. It's the holy grail that's always just over the horizon.

While nations and commercial companies have taken evolutionary steps toward that end over the decades, especially in recent years, they have so far fallen short of a true paradigm shift that would bend the cost of launching heavy payloads downward to a revolutionary degree.

Enter SpaceX, which plans to fly its reusable Starship design on its first orbital flight, possibly in May. This will be the first end-to-end test flight of the two-stage rocket consisting of the Super Heavy booster and Starship upper stage that would eventually carry astronauts and even tourists. If all goes well, the flight will demonstrate just how different this heavy-lift rocket is from all those that came before it.

After blasting off from Boca Chica, Texas, Super Heavy's 33 Raptor engines will boost the unoccupied Starship on its way to orbital altitude and then separate and descend with the aid of its liquid-methane-and-oxygen-fueled engines for what the company vaguely calls a "soft landing" in the Gulf of Mexico. This would be in contrast to Elon Musk's description of Super Heavy someday returning to Boca Chica to be caught by the chopstick-like arms of the "Mechazilla" recovery tower now under construction. Once separated from Super Heavy, Starship will continue on toward orbital altitude, propelled by six Raptors, and once at that altitude, cut off its engines and begin an unpowered decent toward the Pacific Ocean. This will involve a technique demonstrated by a series of prototype flights in 2020 and 2021 in Texas in which the Raptors reignited to flip the craft base first. This time, though, Starship will attempt a soft landing northwest of Kauai in the Hawaiian islands. SpaceX has not specified whether plans call for a splashdown or landing on some kind of vessel. FAA filings indicate that SpaceX may not recover the Starship and Super Heavy from the first flight, but operational plans call for reflying them.

If the test launch succeeds, it will represent a key step toward bending space access cost downward to a revolutionary degree. Demonstrating that expensive components can be returned to Earth will likely inspire other companies to adopt reusability.

The space community's path over the decades to reach this point has been wrought with brambles, blind corners and dead ends, but it's a fascinating history.

It all began when the Apollo lunar missions of the 1960s and early '70s generated excitement about space travel but also confirmed that continuation of single-use throwaway vehicles for space access was not sustainable. Just over a year after the historic Apollo 11 landing, then-U.S. President Richard Nixon decided to truncate the original plan for 10 lunar landings, making the last mission Apollo 17 in December 1972. Astronauts had experienced a brush with death in 1970 during the Apollo 13 mission, and even the truncated program ended up costing $25.4 billion, nearly $165 billion in today's dollars. In January 1972, Nixon directed NASA to build a reusable spacecraft to ferry people and cargo to low-Earth orbit and back. The space shuttle design NASA selected in March of that year became the iconic architecture now recorded in history: On ascent, a reusable orbiter would receive fuel from a large expendable external tank, plus additional thrust from two solid rocket boosters whose cases would be fished out of the sea and reflown.

In the following years, NASA sought to drive launch costs down by encouraging the private sector to develop its own launch vehicles. Although NASA had been contracting with commercial entities since its inception in 1958, it had treated these sources more as vendors for needed parts while retaining absolute control over all aspects of its programs — a process that had proved costly. So in 1983, then-President Ronald Reagan signed National Security Decision Directive-94, "Commercialization of Expendable Launch Vehicles," which initiated greater commercial involvement in launch vehicle development. NASA also established the Office of Commercial Programs in September 1984 to encourage the private sector to become even more involved in space activities. That year also saw Congress pass the Commercial Space Launch Act for the sole purpose of inspiring industry to design and build their own launch vehicles.

The space shuttle Challenger tragedy in 1986 accelerated the push toward commercial development of expendable launch vehicles and encouraged commercial enterprises to advocate for a more active role. And while Reagan temporarily banned commercial payloads from flying on shuttle flights after the Challenger loss, that hiatus did not preclude private companies from actively developing their own expendable launch vehicles for those customers.

On the reusable front, research received a significant boost from the dissolution of the Soviet Union in 1991 and the ensuing end of the Cold War. The reason: The excess government dollars or "peace dividend" provided a new opportunity for longer-term research. With NASA funding, various aerospace companies began experimenting with different launch vehicle concepts in support of NASA's desire for assured access to space, specifically focusing on conventional propulsion systems that would launch two stages to orbit. Early participants were Boeing, Lockheed Martin and Orbital Sciences Corp., subsequently bought by Northrop Grumman.

A small victory for partial reusability came in 1990 with the first launch of Orbital's Pegasus air-launched

rocket, in which a modified Lockheed L-1011 airliner carried the rocket and payload to an altitude of 40,000 feet and released them. Although limited to payloads of 454 kilograms, the design was a significant step toward a revolutionary paradigm shift in launch capability and demonstrated the significant cost savings of a multiuse vehicle.

A motivator for this work was that the space shuttle fleet had not succeeded in reducing launch costs as hoped. Furthermore, each orbiter required more refurbishment between flights than originally hoped.

So in an attempt to provide an alternative to the space shuttle, NASA in 1996 awarded Lockheed Martin a contract to develop the X-33, aiming for a single-stage-to-orbit vehicle powered by a linear aerospike engine, a design notable for its lack of a conventional nozzle. If all went as planned, the X-33 would avoid costly launch vehicle staging. But after the program experienced a long series of technical difficulties — including weight growth and evidence that the vehicle would experience flight instability if it ever took to the air — NASA canceled the effort in 2001 without ever flying the demonstrator.

The troubles experienced by the X-33 developers suggest to us that at least two launch stages comprising conventional propulsion, as in the Starship design, remain required for a truly cost-effective vehicle. Matters may change someday, but not today.

The experience gained from these earlier efforts stimulated a wider commercial participation. After extensive lobbying by the aerospace industry, in November 2005, NASA established the Commercial Crew and Cargo Program Office, C3PO, for the purpose of encouraging growth of the private spacecraft sector, which in turn established the Commercial Orbital Transportation Services program, COTS. Although C3PO managed COTS, NASA itself backed off from its normal hands-on approach and assumed the role of an investor and adviser to nurture development of commercial space transportation systems.

This was a new way of doing business, in short a new paradigm. The newness was NASA becoming a partner with industry and not its overseer — all for the purpose of reducing costs for space access, although the focus was still not on reusable space launch vehicles. COTS created a pathway for the Commercial Crew Development program to establish astronaut-ferrying services to and from the International Space Station. Awarding contracts to Boeing and SpaceX in 2014 to provide those services marked a milestone toward restoring U.S. ability to reach ISS with American-made rockets.

This renewed commercial focus freed NASA to concentrate its in-house propulsion funds on research for advanced in-space propulsion, such as electric propulsion that's capable of delivering very high specific impulses. Development of space access capability itself was left to the efforts of commercial enterprises.

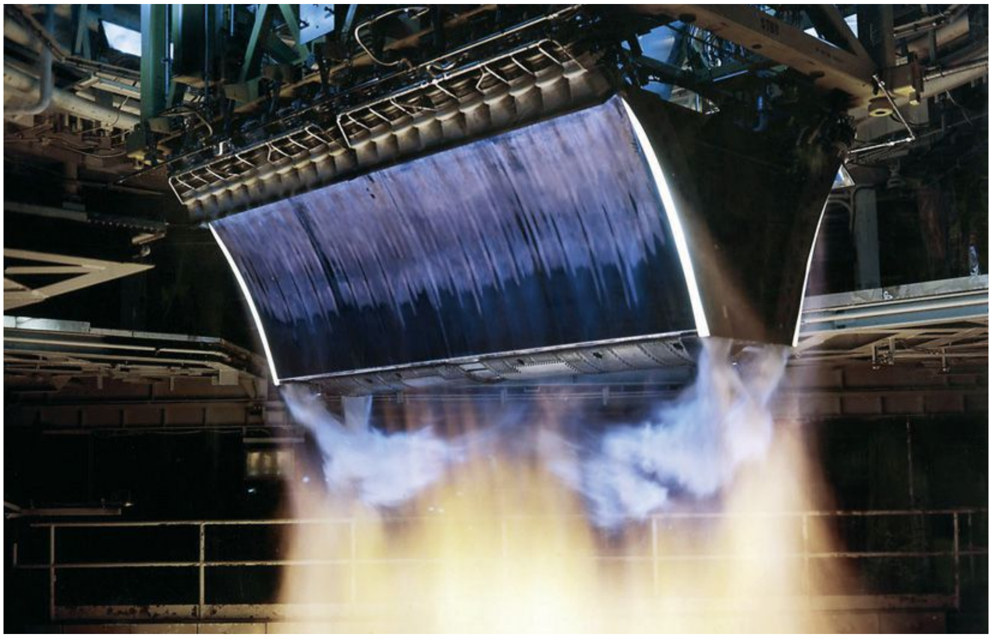
All of these commercialization efforts to reduce the cost per kilogram of reaching space, while significant, still remained evolutionary. None of these addressed the "elephant in the room" — the need for a given launch vehicle to be flown multiple times and for such reusability to become the norm across the launch industry. The logic was inescapable: No one would build a 747 aircraft, fill it with passengers in Los Angeles, fly it to New York and then throw it away. The only way to bend the space access cost curve in a

▲ SpaceX's SN10 Starship prototype descends back toward Boca Chica, Texas, in a March 2021 test flight. It marked the first time a Starship prototype managed to flip and land base first, but the touchdown was too hard and SN10 exploded. Two months later, a different prototype landed without incident for the first time.

SpaceX

▶ NASA canceled the X-33 program before the wedge-shaped demonstrator ever flew, but engineers conducted a handful of ground tests with the two prototypes Rocketdyne built of the plane's linear aerospike engine design. The engine pictured here was fired for 30 seconds during a 2001 ground test at NASA's Stennis Space Center in Mississippi.

NASA



revolutionary way is through the multiple use of the same launch vehicle.

The vertical launch and landing technology adopted by SpaceX and Blue Origin was inspired by development of two Delta Clipper-Experimental, or DC-X, low-altitude demonstrators. The U.S. Air Force provided early funding, but the program was later transitioned to NASA. McDonnell-Douglas started construction of the first vehicle in 1991 and flew it for the first time at White Sands in New Mexico in 1993. The DC-XA, as the second vehicle was called, made the program's final flight in July 1996, when it reached an altitude of 3,140 meters. Although the program ended, its influence on the industry did not.

Various concepts of reusable launch vehicles began to arise, most notably from Blue Origin, Northrop Grumman, SpaceX and United Launch Alliance. SpaceX, however, emerged as the clear leader toward reaching this goal. SpaceX has relied heavily on clever reconfiguring of existing technology and has funded the vast majority of Starship development with its own internal resources. NASA, however, has become a very effective partner to SpaceX by funding needed high-risk development along the way, most recently awarding a $2.9 billion contract to build a lunar lander version of Starship that the agency would certify.

An exception to the push for reusability has been NASA's development of the Space Launch System moon rockets, initiated in 2011 with a contracting team. Unlike Starship with its Super Heavy booster, SLS's core stage won't be recoverable. Given that NASA expects the early SLS launches to cost $4.1 billion each, the agency is missing an opportunity to save billions of dollars through reusability.

In an attempt to establish leadership in multiple-use launch systems, SpaceX after three attempts recovered the booster stage of a Falcon 9 for the first time in 2015 by landing it at Cape Canaveral, Florida. And as of this writing, per the company's website, SpaceX has launched 148 Falcon 9s, and 88 of those were with previously flown boosters. This accomplishment set SpaceX above its competition for reusable launch vehicles and put it into a favorable position for the development of the Starship.

The Falcon feat was indeed a groundbreaking accomplishment that demonstrated a near order-of-magnitude cost savings for payload insertion into low-Earth orbit. SpaceX has estimated a Falcon 9 launch cost of $2,700 per kilogram versus $20,000 per kilogram if launched by conventional means. And those costs should continue to go down as more companies adopt reusability and competition increases.

The Falcon 9 achievement isn't just about dollars saved today. Now that we know that spent stages can land on drone barges or fly back to the launch site, this opens the door to creative new architectures. For instance, a two-stage winged rocket plane could operate from a conventional airport, as we suggested last May in this magazine. Each winged stage would fly back to its airport of origin to be reassembled, refueled and reused. This scenario would both simplify operations and make permanent a revolutionary favorable bend in the space access cost curve.

In the words of Konstantin Tsiolkovsky, the father of theoretical and applied astronautics, "The Earth is the cradle of humanity, but one cannot live in the cradle forever." Humans are destined for the cosmos, and we will find a way. ★

Philip I. Moynihan retired in 2007 after 45 years as an aerospace engineer, first at Rocketdyne in California and later at the NASA-funded Jet Propulsion Laboratory. He holds a doctorate in mechanical engineering from the University of Southern California.

Eugene A. Ustinov retired in 2021 after 50 years as a remote sensing scientist at the Space Research Institute and Institute of Atmospheric Physics in Russia, then at NASA's Goddard Space Flight Center in Maryland and later at the NASA-funded Jet Propulsion Laboratory in California. He holds a doctorate from the Space Research Institute in Russia and a doctorate from Tartu University in Estonia, both in the area of theory of radiative transfer and application to remote sensing.

PROTECTING YOUR INNOVATIONS

Aerospace is a hot market full of groundbreaking aviation and space startups. A surprising number of these companies lack plans to protect their intellectual property. History shows that's a mistake. Graham Phero, Robert Greene Sterne and Andrew Stevens of Sterne Kessler, an intellectual property law firm in Washington, D.C., explain.

BY GRAHAM PHERO, ROBERT GREENE STERNE AND ANDREW STEVENS

While established corporations in the aviation and space sectors have plans for protecting their intellectual property, too many startups forego the opportunity to protect their critical innovations from competitors and simultaneously enhance efforts to recruit and retain key talent as well as attract investor interest and future funding.

The earliest actors in aviation in the United States quickly realized the value of protecting intellectual property. As efforts turned from development of gliders to powered flight in the late 19th century, aviation scientists and engineers openly collaborated to encourage progress. Self-taught engineer Octave Chanute shared information about his team's glider flights with the Wright brothers during the run-up to their 1903 powered flight, and both began to commercialize their innovations. The Wright brothers in 1906 were granted U.S. Patent No. 821,393 for a flying machine. While this patent was generally directed

toward their unpowered glider, the patent protected key mechanisms for controlling an aircraft in flight, applicable to many early aircraft.

In the next few years, the number of global patent filings in aerospace (mainly in France, Germany, the United Kingdom and the United States) reached around 1,500 per year. This number of patents was not surpassed for most of the 20th century — in fact, with the start of World War I the number of patent filings in aerospace sharply declined and then plateaued. Government spending drove the industry, and corporations confidentially kept many of their innovations as trade secrets or relied on government contracts to protect this intellectual property.

Industry data shows that having a sound intellectual property plan remains valuable today. This is evidenced by established corporations in the aerospace industry. In early 2022, Boeing, with its large patent portfolio, had a valuation of some $150 billion and over 21,000 active U.S. and foreign utility and design patents. Likewise, Lockheed Martin had a valuation of nearly $120 billion and over 5,500 active U.S. and foreign utility and design patents.

Now consider two startups, Astra Space of California and Exodus Space of Colorado. Astra Space provides launch services from Alaska and Florida, delivering payloads of up to 500 kilograms to orbit. In April 2022, and taking into account a failed launch, Astra Space was valued by Yahoo Finance at around $800 million. Despite its innovations, Astra Space had two public U.S. patent filings as of this writing. Exodus Space is in a similar technology space and, while still raising funds, had only three public U.S. patent filings.

SpaceX illustrates a transition case between the extremes of established aerospace corporations and startups. In October, CNBC reported SpaceX at a valuation over $100 billion after a share sale by existing investors in late 2021. Founder Elon Musk once stated that SpaceX had "essentially no patents. … Our primary long-term competition is in China — if we published patents, it would be farcical, because the Chinese would just use them as a recipe book." However, by 2018, this was no longer the case. SpaceX is now developing its patent portfolio in the satellite area, with some 50 U.S. patent filings directed to antenna systems, satellite constellations and metal honeycomb materials. Meanwhile, like Boeing and Lockheed Martin, SpaceX holds many contracts with NASA, including a Commercial Crew Transportation Capability contract.

The key question for startup corporations is: How can they maintain their innovation edge and grow valuations relative to established competitors? Investors are keen to learn the answers to that very question. And more specifically, what is the time and cost involved for a competitor to enter the technology space and try to take your market share, and what prevents them from doing so? While lead time and know-how go a

▲ Astra Space, shown here launching three satellites to sun-synchronous orbit from Alaska, is emblematic of startups with lots of potential but few patents.

Astra Space

▲ SpaceX's approximately 50 patent filings include the design of ground antennas that transmit signals to and from Starlink satellites. This photo from a Falcon 9 fairing shows 60 Starlinks shortly before deployment in 2019.

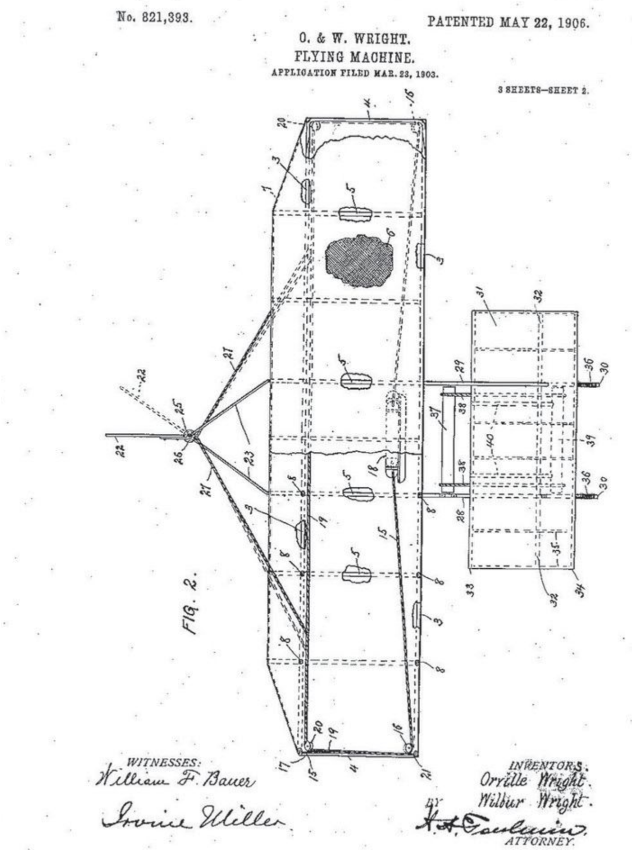
SpaceX

long way at first, a robust intellectual property plan including patents — a public government-issued monopoly — and trade secrets — a company's internal treatment of innovations kept confidential — is what sets a company up for long-term success and keeps future competitors at bay. A startup corporation must have an intellectual property plan and execute it as early as possible in order to build and maintain its market lead. Such a plan sets forth a global strategy, timelines, budgets and intellectual property objectives that can then be shared with management and investors.

Patents, for example, offer utility and design protection. Utility patents protect the operational aspects of a technology, while design patents and registrations protect the ornamental aspects. The patent system advances technological developments in industry through public disclosure. In exchange for teaching the public the technical details of an innovation, the government grants that inventor the right to exclude others from making, using, offering for sale or selling the innovation. But it is through that public disclosure that others learn from and improve upon the invention or develop their own alternative designs. Both utility and design patents provide for civil enforcement against competitors and provide predictable licensing opportunities to a patent owner. Patent rights expire 20 years after filing.

Trade secret protection is another important piece of an intellectual property plan in the aerospace industry and often protects a startup's most valuable assets. Unlike a patent, a trade secret is confidential information that is never shared with the public. A trade secret must be identified and maintained as secret by the company. If the confidential information is improperly obtained by another entity, then the company may seek legal remedy under the relevant state or federal trade secret law. A company can choose to internally maintain documented descriptions of innovations they maintain as trade secrets, and should, but these documents must also remain secret to external entities. Trade secret protection provides for civil and criminal enforcement, can be more cost effective than patent protection and lasts forever — or at least as long as the startup maintains the information as secret. But if the trade secret information is discovered lawfully, the company maintaining that trade secret may be left without means to protect its innovations.

As two sides of the same legal coin, patent and trade secret protection are both used as part of an intellectual property plan to protect corporate assets and gain a competitive advantage. Not all important innovations are most effectively protected the same way using intellectual property procedures. Some innovations can be easily detected when stolen by a competitor, whereas others are nearly impossible to identify when improperly expropriated. By the same token, some innovations can be easily reverse engineered, whereas others are essentially impossible to determine without explanation. These factors must be considered when deciding whether optimal intellectual property protection rests with trade secrets, patents or both in various jurisdictions around the world. Developed and modified as a



One of three drawings submitted by Orville and Wilbur Wright in their 1903 patent application for their unpowered glider flying machine.

United States Patent and Trademark Office

company's needs change, an intellectual property plan is the management tool for making these determinations in a disciplined and market-driven manner. Having the intellectual property plan increases the effectiveness of the intellectual property program of the startup, maximizes intellectual property value and minimizes intellectual property risk. The result is a greater return on investment for the intellectual assets of the startup, which inures to the benefit of the shareholders and other stakeholders of the startup.

Given the rapid pace of innovation, startups also have an opportunity to create industry standards that must be followed by others — for example, when executing on a government contract. To the extent innovations resulted in the industry standard, that startup can patent and license their intellectual property to others to generate additional revenue streams.

But before startups can protect their intellectual property, they must first identify that property and determine the proper protection vehicle — all in line with their intellectual property plan. This is where many startups fail. Rather than make a conscious decision, they allow their innovations to linger and often do not pursue any type of protection whatsoever. In the case of trade secrets, many of these startups fail to implement adequate safeguards and instead watch their valuable trade secrets walk out the door through normal attrition and employee turnover. This is because as soon as the trade secret becomes available to the public, through accident, wrongdoing or otherwise, the innovation loses protection. Such inattention can significantly hamstring protection of market share and future revenue streams.

Additionally, patent filings are an externally visible measure of a startup's innovative culture. So, without the purposeful public disclosure of innovations through patent filings, startups may struggle to hire and retain leading innovators seeking recognition. Thus, startups in the aerospace industry should create and execute on their intellectual property plan in strategic countries using a team of diverse technical and legal specialists. A responsive intellectual property team will recognize the importance of patents, trade secrets, secrecy orders and licensing schemes in and outside the aerospace industry.

And legal experience is needed in all areas of the law, including customs, arms regulation, international organizations and contract law. With this globalized intellectual property plan, startups and their innovations in the aerospace industry will thrive. Without it, startups often pursue protection on less valuable intellectual property assets, or worse, forgo protection altogether. ★

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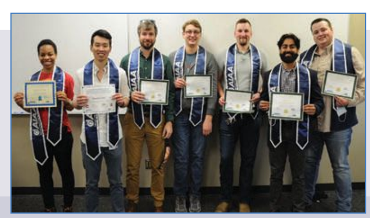

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Other Important Numbers: Aerospace America / Catherine Hofacker, ext. 7587 • AIAA Bulletin / Christine Williams, ext. 7575 • AIAA Foundation / Alex D'Imperio, ext. 7536 • Book Sales / 800.682.AIAA or 703.661.1595, Dept. 415 • Communications / Rebecca Gray, 804.397.5270 • Continuing Education / Jason Cole, ext. 7596 • Corporate Programs / Nancy Hilliard, ext. 7509 • Editorial, Books and Journals / Michele Dominiak, ext. 7531 • Exhibits and Sponsorship / Paul doCarmo , ext. 7576 • Honors and Awards / Patricia Carr, ext. 7523 • Integration and Outreach Committees / Angie Lander, ext. 7577 • Journal Subscriptions, Member / 800.639.AIAA • Journal Subscriptions, Institutional / Online Archive Subscriptions / Michele Dominiak, ext. 7531 • K–12 Programs / Alex D'Imperio, ext. 7536 • Media Relations / Rebecca Gray, 804.397.5270 • Engage Online Community / Luci Blodgett, ext. 7537 • Public Policy / Steve Sidorek, ext. 7541 • Section Activities / Lindsay Mitchell, ext. 7502 • Standards, International / Nick Tongson, ext. 7515 • Technical Committees / Angie Lander, ext. 7577 • University and Young Professional Programs / Michael Lagana, ext. 7503

We are frequently asked how to submit articles about section events, member awards, and other special interest items in the AIAA Bulletin. 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 AIAA Bulletin Editor.

Calendar

FEATURED EVENT

27 JUNE–1 JULY 2022

Chicago, IL, and Online

There's no shortage of challenges facing the aviation industry: the supply chain is at a pivotal point, there is a downturn in demand, environmental sustainability is critical, and experts warn of a talent shortage. We have the opportunity to reset expectations, redefine roles, and accelerate change. Join us as we explore the next golden age of aviation with the theme, Challenging Times, Unique Opportunities.

aiaa.org/aviation

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2022			
2–5 May	Applied Space Systems Engineering Course	ONLINE (learning.aiaa.org)	
3–4 May	OpenFOAM CFD Foundations Course	ONLINE (learning.aiaa.org)	
3–5 May*	6th CEAS Conference on Guidance, Navigation and Control (EuroGNC)	Berlin, Germany (eurognc2022.dglr.de)	31 Oct 21
4–27 May	Electrochemical Energy Systems for Electrified Aircraft Propulsion Course	ONLINE (learning.aiaa.org)	
10 May–30 Jun	Human Spaceflight Operations: Lessons Learned from 60 Years in Space Course	ONLINE (learning.aiaa.org)	
16–17 May*	AIAA SOSTC Improving Space Operations Workshop 2022	Virtual Event (https://isow.space.swri.edu)	
16–19 May*	26th Aerodynamic Decelerator Systems Technology Conference and Seminar (ADSTCS)	Toulouse, France (https://earthlydynamics.com/adst-2022)	
17–26 May	Digital Engineering Fundamentals Course	ONLINE (learning.aiaa.org)	
24–25 May	OpenFOAM External Aerodynamics Course	ONLINE (learning.aiaa.org)	
1–22 Jun	Optimal Control Techniques for Unmanned Aerial Vehicles (UAVs) Course	ONLINE (learning.aiaa.org)	
6–9 Jun	Designing Space Missions Course	ONLINE (learning.aiaa.org)	
7 Jun	OpenFOAM CFD Aeroacoustics Course	ONLINE (learning.aiaa.org)	
8 Jun	OpenFOAM CFD Dynamic Mesh Modeling Course	ONLINE (learning.aiaa.org)	
8 Jun	ASCENDxSummit: Sustaining Space for the Next Generation	Online (ascend.events)	
14–17 Jun*	28th AIAA/CEAS Aeroacoustics Conference	Southampton, UK (aeroacoustics2022.org)	12 Jan 22

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.).

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2022			
15 Jun–10 Aug	Missile Design: A Comprehensive Guide to Propulsion, Aerodynamics, Weight, Flight Performance, Guidance, Lethality, System Engineering, and Development Course	ONLINE (learning.aiaa.org)	
25–26 Jun	7th AIAA Drag Prediction Workshop ("DPW-VII: Expanding the Envelope")	Chicago, IL	
26 Jun	2nd AIAA Workshop for Multifidelity Modeling in Support of Design & Uncertainty Quantification	Chicago, IL	
27 Jun–1 Jul	AIAA AVIATION Forum	Chicago, IL	10 Nov 21
16–24 Jul*	44th Scientific Assembly of the Committee on Space Research and Associate Events (COSPAR)	Athens, Greece (cospar-assembly.org)	11 Feb 22
19 Jul–11 Aug	Design of Electrified Propulsion Aircraft Course	ONLINE (learning.aiaa.org)	
7–10 Aug*	AAS/AIAA Astrodynamics Specialist Conference	Charlotte, NC	1 Apr 22
4–9 Sep*	33rd Congress of the International Council of the Aeronautical Sciences (ICAS 2022)	Stockholm, Sweden (icas2022.com)	10 Feb 22
13–22 Sep	Aircraft Reliability & Reliability Centered Maintenance Course	ONLINE (learning.aiaa.org)	
18–22 Sep*	73rd International Astronautical Congress	Paris, France (iac2022.org)	
27 Sep–3 Nov	Introduction to Aviation Data Science Course	ONLINE (learning.aiaa.org)	
28 Sep–21 Oct	Fundamentals and Applications of Pressure Gain Combustion Course	ONLINE (learning.aiaa.org)	
4–20 Oct	Overview of Python for Engineering Program Course	ONLINE (learning.aiaa.org)	
4–27 Oct	Propeller Aerodynamics for Advanced Air Mobility: Fundamentals and Integration Effects Course	ONLINE (learning.aiaa.org)	
24–26 Oct	ASCEND Powered by AIAA	Las Vegas, NV	7 Apr 22
2023			
23–27 Jan	AIAA SciTech Forum	National Harbor, MD	1 Jun 22
11–13 Apr	AIAA DEFENSE Forum	Laurel, MD	18 Aug 22
12–16 Jun	AIAA AVIATION Forum	San Diego, CA	
27–30 Jun*	ICNPAA 2021: Mathematical Problems in Engineering, Aerospace and Sciences	Prague, Czech Republic (icnpaa.com)	
2–6 Oct*	74th International Astronautical Congress	Baku, Azerbaijan (iac2023.org)	
23–25 Oct	ASCEND Powered by AIAA	Las Vegas, NV	

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

● AIAA Continuing Education offerings

2022 Sperry Award Winner Honored for Advancing In-Space Additive Manufacturing

Lawrence Sperry Award Recognition

The Lawrence Sperry Award recognizes a notable contribution made by a young person, age 35 or under, to the advancement of aeronautics or astronautics. **AIAA Associate Fellow Michael Snyder** was recognized: "For outstanding and notable contributions to advance in-space additive manufacturing to ensure safer, sustainable spaceflight missions and manufacturing industrial products to benefit Earth." As noted in his award nomination, "Snyder's contributions to the industry in the areas of spaceflight technology are significant and have had a notable impact on the trajectory of space exploration. NASA, DARPA, NRO and other agencies have benefited from his expertise to inform various space manufacturing programs. His technical expertise combined with his passion for the advancement of space exploration and his commitment to bridging the gap for the next generation of engineers and aerospace professionals" are what made him an ideal candidate for the Lawrence Sperry Award.

Driven by a Fascination with Space Exploration

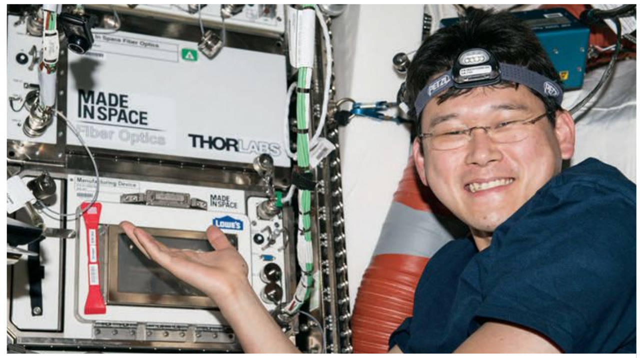
Snyder honestly cannot remember a time when he wasn't interested in aerospace. He loved anything and everything about space exploration, particularly human exploration. "I enjoyed just watching Earth views from shuttle missions that would loop on NASA TV and all the programming they built around space exploration," commented Snyder. "My immediate family did a great job in nurturing my interests, including having extreme amounts of patience with me after my many ad hoc discovery projects that involved taking appliances apart and attempting to put them back together after I thought I figured out how they worked." He added, "I was also taken to the library frequently and enjoyed reading nonfiction subjects ranging from astronomy to shipwrecks … I was fueled to dedicate [my] future in the endeavor to expand the capabilities of spaceflight and enable people to live and work in space permanently."

Snyder knew from as young as second or third grade that he wanted to study aerospace engineering, and he noted, his "home state of Ohio has a great aerospace infrastructure, so I had a few good in-state university choices." He attended what he considered and still considers to be the best—Ohio State University.

Developing the Skills to Start His Own Company

During his time at Ohio State, Snyder took advantage of the aerospace-related clubs on campus, "sometimes to the detriment of my classwork." "[I] participated in the aircraft and rocket design teams and had the opportunity to lead them in my junior and senior years. I founded the Electronic Controls Club on campus to facilitate the development of some guidance systems for the rocket team. I also was involved and eventually led the campus AIAA student branch." He noted that these extracurricular clubs were what developed his management skills, adding, "Those skills vastly improved with the help of the clubs' advisors, mainly Dr. Jack McNamara." Snyder is convinced his early management of engineers would have been a much harder experience "without those experiences and tutelage."

An internship opportunity with an aircraft engine simulation company helped inspire the later application of his Made In Space internship experiences and provided Snyder first-hand insights on the do's and don'ts of those opportunities.



He credits his graduate advisor, Dr. M. J. Benzakein, for introducing him "to the experience of developing payloads for the ISS with a project he handed over" to complete, "resulting in the on-orbit investigation of the synthesis of nanocrystalline ceria through varying gravitational fields. … That project gave me the incredible experience of designing, building, and qualifying hardware that would operate on the ISS."

Inspiration

Snyder noted that many people have influenced him in his work over the years. He remarked, "I was always inspired by the folks in mission control and engineers enabling space exploration to take place in my adolescence. I connected to the Apollo folks the most; this was probably due to the available information at the time. Chris Kraft, Tom Kelly, and fellow Ohio native Gene Kranz were all inspirations for me, and I can't tell you how many times I read their books growing up."

He added that at college, he had "fantastic mentors. Anita Gale and the late Dr. Eric Rice took me under their wing[s] when it came to AIAA technical activities and really made me feel welcome and allowed me to contribute. The late Dr. Gerald Gregorek at Ohio State really educated me on proper design cycles and alternative ways to view problems both in class as well in the design teams. Mike Johnson educated me greatly in all topics related to payloads, including showing me the most effective ways to present data necessary for qualification. The late Allan McDonald always took my phone calls and mentored me on his views on appropriate safety cultures, especially when the company started to scale up. I think the most influential person during my professional career has been Dr. John Grunsfeld. He brings a perspective that is leaps and bounds beyond any other single source. His guidance has been invaluable with building and running larger programs."

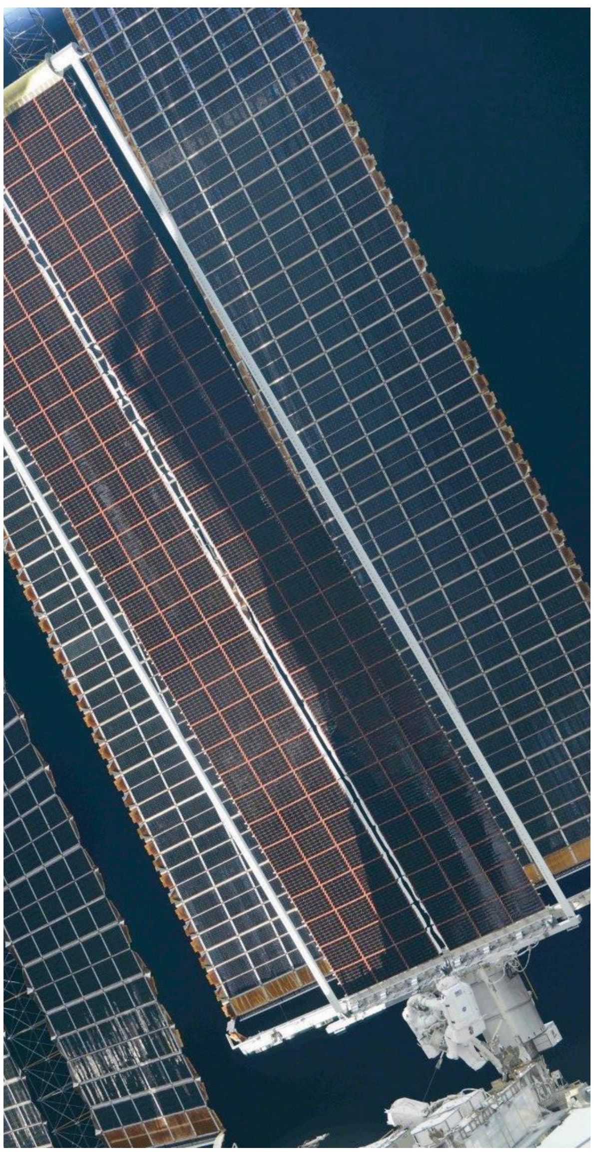
AIAA Membership

When asked about the value of AIAA membership, Snyder said that his participation in the student branch beginning as a freshman led him "to access the technical activities of the … national group. I love learning. I loved going to conferences to hear about new work and concepts while presenting on my own, and I love being around some like-minded folks who had a passion for technical development and innovation." He became a member of the Space Settlement Technical Committee in 2009, while still an undergraduate. He took on the positions of secretary, then co-chair, and finally chair in 2017. He noted, "The bulk [more than 20] of my technical publications have been through AIAA, which started while I was still an undergraduate student."

Made In Space

Having started his first company providing "mainly consulting services with an eye toward space" as an undergraduate, his work "greatly expanded during graduate school after teaming up with the other co-founders of Made In Space." The company's mission was to bring manufacturing and industry to space and create a future where humans are enabled to live and work in space by eliminating the reliance on Earth resupply and spares.

Under Snyder's technical leadership, Made In Space went on to produce and operate the first additive manufacturing hardware in space, build and operate the first commercial manufacturing hardware for use in space, produce the first optical fiber in space, and became the first company to commercialize space-enabled materials.



Snyder remarked on the untraditional journey that the business has taken, “The phrase 'Iterate early and iterate often' applies to both design and business alike. The path we’ve been on has taken many routes that were not predictable at the beginning. ... we chose to be agile, to meet customers’ needs while still maintaining objectives toward the end goal: long-term habitation and space-enabled technologies.”

He added, “we set out to do things that never have been done before and there are learning opportunities that make the approach better after modification. We did not take on investment at the beginning of the company so we could maintain that agility and be responsive toward ever-changing demands. We were very fortunate to have a lot of people believe in us, especially early on at NASA Marshall Space Flight Center. They also had a vision that was [well aligned] with our own to bring manufacturing to space. My career has taken twists and turns that took me places that I could not imagine at the beginning or even later on. That’s really part of the excitement. I cannot wait to experience what is to come.”

Looking to the Future

After Made in Space was acquired by Redwire Space in 2020, Snyder became chief technology officer. The company has now launched over 35 payloads and pieces of hardware on 20 missions, including the upgraded International Space Station solar arrays. When asked what he thinks he’ll be working on in the future, Snyder responded, “I look forward to the changing landscape and the new challenges that will present themselves. I do hope that in the decades to come, more space-enabled products are investigated and monetized for use back here on the ground. We’ve been successful on a couple of materials that we’ve tried out, but there are hundreds more that should be looked at. It truly is in its infancy as an industry. I also hope that in situ resource utilization (ISRU) becomes commonplace. The only way sustainable exploration and habitation can occur is living off the land. I think the ISRU technologies developed for space will benefit conditions here on Earth in the long term. We need to be more efficient with how we use materials and energy and what better place to develop those technologies than in space, where it is an absolute necessity, all the time.”

MAKING AN IMPACT

AIAA, Estes Industries, and NSTA Launch New Aerospace Education Initiative: Exploration Generation

AIAA, Estes Industries, and the National Science Teaching Association (NSTA) have joined together to inspire the next generation of scientists and engineers through a new, multi-year initiative that will bring research-based aerospace education to thousands of classrooms nationwide. Exploration Generation (ExGen) will provide K-12 educators with free lesson plans and curriculum storylines to help guide students as they explore various concepts in aerospace, engineering, and rocketry. High-quality professional learning experiences will also be developed to support teachers' use of the ExGen instructional materials.

To help educators provide a more collaborative, student-centered learning environment where ideas are accessible and engaging for all students, each lesson plan, called NSTA Daily Dos, and the curriculum storylines, called NSTA Units, are grounded in sensemaking. Through this approach, students actively engage in a learning experience to make sense of phenomena in a way that aligns with their natural curiosity. In May, ExGen will unveil its first three Daily Dos developed for the middle school level. The NSTA Unit, designed for grades 6-8, will be available in October. ExGen will expand with additional resources for elementary and high school educators next year. Professional learning for educators will begin this fall with additional programs available in the future.

To ensure this program is widely accessible to as many students as possible, Estes will match the AIAA contribution to the program in the first year of launch through in-kind donations to participating schools and continue in all subsequent years.

In addition, Estes will manage a grant program to provide eligible Title 1 schools with funding to purchase the supplies needed to facilitate these lessons in the classroom. Details on how to apply will be announced later this year.

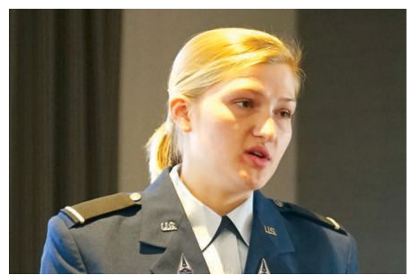
For more information about how to get involved with AIAA and make an impact please visit aiaa.org/foundation or contact Alex D'Imperio, alexandrad@aiaa.org.

AIAA Announces 2022 Regional Student Conference Winners

AIAA is pleased to announce the winners of six of the 2022 Regional Student Conferences. The Institute holds conferences in each region for student members at the undergraduate and graduate levels, and this is the first year since the program's inception that High School Members were invited to present. The student conferences are a way for students to present their research and be judged on technical content and presentation skills by AIAA members working in the aerospace industry. The students also had a chance to network with aerospace professionals and attend special events. Lockheed Martin was the generous sponsor of these conferences, in addition to several other regional sponsors.

More than 170 papers were presented by university and high school students across all six regions, with over 500 students and professionals in attendance. The AIAA Region VII Student Conference will be held in fall 2022.

The first-place university student winners in each undergraduate, graduate, and team categories (listed below) are invited to attend and present their papers at the AIAA International Student Conference, to be held in conjunction with the 2023 AIAA SciTech Forum in National Harbor, MD, 23-27 January.



Region I Winners

High School Category

1st Place – "Breaking Statistics of Airlines Sanitation Efforts," Kristin Nelson, Natalie Catalano, and Ella Bianco, It's a Girls World (Carneys Point, NJ)

Undergraduate Category

1st Place – "Estimation of UAS Relative Position and Orientation Using Multiple Parwise Range Measurements," Ezra Bregin, University of Maryland (College Park, MD)

2nd Place – "Viability in Electric Propulsion in Small Satellites for Active Debris Removal," Yaw Tung Tan, Kelly Irons, and Elaine Petro, Cornell University (Ithaca, NY)

3rd Place – "Trajectory Optimization for Refueling Geosynchronous Satellites," Evangelina Evans, Pennsylvania State University (State College, PA)

Masters Category

1st Place – "Use of Naphthalene Sublimation Technique to Study Solid Fuel Regression," Grace Hall, Virginia Polytechnic Institute and State University (Blacksburg, VA)

2nd Place – "Large Deformation Bending of Ultralight Deployable Structure for Nano and Micro Class Satellites," Jimesh Bhagatji and Oleksandr Kravchenko, Old Dominion University (Norfolk, VA)

3rd Place – "QCM Temperature-Frequency Characterization for Plume Measurement Application," Arthur Chadwick and Elaine Petro, Cornell University (Ithaca, NY)

Team Category

1st Place – "Jovian Autonomous Sailplane of Persistent Exploration and Research (JASPER)," Joseph Malach, Edward Luthartio, Haley Parker, Sydney Kwitowski, Aiman Alobah, Alexander Hertz, Sayad Asif, Javid Bagandor, University at Buffalo, State University of New York (Buffalo, NY)

2nd Place – "Development of Spectroscopic Measurement Systems of Investigating Scramjet Cavity Flameholding," Andrew Metro, Spencer Barnes, Owen Petito, and Chloe Dedic, University of Virginia (Charlottesville, VA)

3rd Place – "Design and Analysis for an Ionospheric CubeSat," Tyler Lizotte, Phillip Durgin, Jeremy Gagnon, Veronika Karshina, Christopher Ritter, Harrison Smith, Drake

Tierney, and Samuel Waring, Worcester Polytechnic Institute (Worcester, MA)

AIAA Aircraft Operations Technical Committee Best Aircraft Operations Paper

"IR Detection System for Application in Wildfire Suppression," Adam Del Colliano, University of Maryland (College Park, MD)

Region II Winners

Undergraduate Category

1st Place – "Development and Fabrication of an Ultrasonic MEMS Anemometer for Use in Low-Pressure Environments," Alexander Reilly, University of Florida (Gainesville, FL)

2nd Place – "Developing a Bio-Inspired Artificial Butterfly Vehicle," Thomas Clark and Chang-kwon Kang, University of Alabama in Huntsville (Huntsville, AL)

3rd Place – "Application of Vibrational Damping on Spacecraft Crew Capsule Design Using Common Aerospace Materials," Kody Parsotan and Seshan Jayapregasham, Embry-Riddle Aeronautical University (Daytona Beach, FL)

Masters Category

1st Place Mike Freeman Award – Investigation of shock-wave Boundary Layer interaction for a Mach 1.8 flow Isolator," Larry Thompson and Michael Atkinson, North Carolina A&T State University (Greensboro, NC)

2nd Place – "View Factors and Busemann Geometry for Ram Accelerator Projectile Design," Connor McGibbony and Eric Booth, Southeastern Louisiana University (Hammond, LA)

3rd Place – "On the Kármán–Pohlhausen Momentum-Integral Approach: Extension to Flow Over a Cylinder with a Variable Pressure Gradient," Rudy Al Ahmar and Joseph Majdalani, Auburn University (Auburn, AL)

Team Category

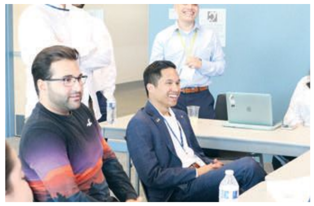
1st Place Stan Powell Award – "Lunar Lava Tube Exploration with CubeRover: Wandering Observer of Lunar Features (WOLF) Rover," Alina Creamer, Brigid Donohue, Bennett Meyer, and Manuel Puyana, North Carolina State University (Raleigh, NC)

2nd Place – "Solid Propellant Arc Combustion for Small Satellite Propulsion," Mallory Roy, Ashley Rivkin, Samuel Lovelace, Jessica Cutler, Nathan Fischer, Victor Robleto, Sean Gunther, Emily Milne, and Abram Murphy, Florida Institute of Technology (Melbourne, FL)

3rd Place – "Racing Drones for STEM Education," Mackenzie Wiles, Bryce Fuson, and Michelle Engelke, Florida Institute of Technology (Melbourne, FL)

Outstanding Branch Activity Category

1st Place – "GT AIAA: Lockheed Martin Case Study," Georgia Institute of Technology (Atlanta, GA)



2nd Place – "Community Outreach in STEM at Florida Tech," Florida Institute of Technology (Melbourne, FL)

3rd Place – "Career Networking Events—Meet the Geeks," Embry-Riddle Aeronautical University (Daytona Beach, FL)

Regional Design Team Category

1st Place – "UofM NERD Team Rover Design," University of Memphis (Memphis, TN)

Freshman/Sophomore Open Topic Category

1st Place – "The Future of Aviation in Zero Carbon Emissions Aircraft," Shannon Tracy, Florida Institute of Technology (Melbourne, FL)

2nd Place – "Lunar Mining of Tritium," Beck Kerridge and Colin Zelasko, Florida Institute of Technology (Melbourne, FL)

3rd Place – "Spacecraft Attitude Control Methods," Jesus Delgado, Florida Institute of Technology (Melbourne, FL)

Region III Winners

Undergraduate Category

1st Place – "Design of an All-Terrain Aerial Robotic Interface (ATARI) as a Collaborative Platform for UAVs," Rebecca Gilligan, University of Cincinnati (Cincinnati, OH)

2nd Place – "A Thermodynamics Analysis for Improvement of Carbon Dioxide Removal Technologies for Space," Meghan Thai, Purdue University (West Lafayette, IN)

3rd Place – "Practical Investigation into the Diffusion Bonding of 316L Stainless Steel with Boron Carbide," Timothy DeFranco and Calvin Chandler, Ohio State University (Columbus, OH)

Masters Category

1st Place – "Optimization of Heat Release within a Dual-Mode Ramjet Using Ignition Delay Energy Source Terms," Francis Centlivre, Wright State University (Dayton, OH)

2nd Place – "Hypersonic Vehicle Conceptual Design Tools Assessment," James Wnek, Wright State University (Dayton, OH)

3rd Place – "Comparison and Uncertainty Quantification of Roof Pressure Measurements in the NIST and TPU Aerodynamic Databases," Erick Shelley, Erin Hubbard, and Wei Zhang, Cleveland State University (Cleveland, OH)

Team Category

1st Place – "Optimization of a Lenz Style VAWT Geometry Utilizing CFD and Genetic Algorithms," Dylan Habig, Timothy Mayer, Trevor Ransbury, Brandon Frymire, Luke McClung, and James Canino, Trine University (Angola, IN)

2nd Place – "Using Classical Control Theory to Optimize Cooldown Phase Propellent Flow Rate for a Nuclear Thermal Rocket Engine," David Giancola, Angel Eng, James Midkiff, Jeff Simko, and Joanna Valentas, Ohio State University (Columbus, OH)

3rd Place – "Investigation of Flow Control for a Piston Positive Expulsion Bipropellant Tank," Raghav Bhagwat, Joseph Januszewski, Chris Petrilla, and John Horack, Ohio State University (Columbus, OH)

Region IV Winners

Undergraduate Category

1st Place – "Design, Analysis, and Manufacture of a Vacuum Pump Sound-Dampening Enclosure," Connor Goodman and Joseph Hernandez-McCloskey, University of Texas at San Antonio (San Antonio, TX)

2nd Place – "Topological Optimization and Generative Design of Drone Structures (A research project to promote a new aerospace educational industry in underdeveloped countries)," Sofia Gutierrez and Juan Ocampo, Saint Mary's University (San Antonio, TX)

3rd Place – "Experimental Evaluation of 14-Inch to 20-Inch Diameter Propellers at Low Reynolds Number Operation," Austin Rouser, Brock Rouser, and Kurt Rouser, Oklahoma State University (Stillwater, OK)

Masters Category

1st Place – "Thermodynamic analysis of nitric oxide in an optically accessible, temperature-controlled gas cell via laser absorption spectroscopy," Benjamin Steavenson, Joseph Hernandez-McCloskey, and Daniel Pineda, University of Texas at San Antonio (San Antonio, TX)

2nd Place – “Deep Neural Network for Measurements in a Non-Uniform Flowfield Using Single Line-of-Sight Laser Absorption Spectroscopy,” Kyle Fetter, Joseph Hernandez-McCloskey, and Daniel Pineda, University of Texas at San Antonio (San Antonio, TX)

3rd Place – “Effects of Surface Roughness on Shock-Wave/Boundary-Layer Interaction using a Hollow Flare Cylinder Model,” Matt Garcia and Christopher Combs, University of Texas at San Antonio (San Antonio, TX)

Team Category

1st Place – “Design of the UTSA High-Enthalpy Shock Tube Facility,” Joseph Hernandez-McCloskey, Benjamin Steavenson, Andrew Alexander, Shelby Franklin, and Carson Bush, University of Texas at San Antonio (San Antonio, TX)

2nd Place – “Engine Redesign and Integration of Rocket Assisted Take-Off on a Small, High-Speed Unmanned Aircraft,” Jeremy Barton, Mahayla Mitchell, Devin Bishop, Tevin James, Mason Jernigan, Callahan Morris, Chase Wilson, Ben Sanford, Romain Bailey, and Cooper Degner, Oklahoma State University (Stillwater, OK)

3rd Place – “Stratospheric Conductivity Balloon Campaign With Accessible Payload Design,” Alexandra Ulinski, Rachel Nathan, Andy Nguyencuu, Carlos Salas, Elizabeth Hernandez, and Edgar Bering, University of Houston (Houston, TX)

Region V Winners

Undergraduate Category

1st Place – “Experimental Verification of the USAFA 1-DOF Dynamic Stability Characterization Capability and Future 3-DOF Cross Coupling Enhancements,” Molly Ellinger, Jacob Szymanski, and Casey Fagley, United States Air Force Academy (Air Force Academy, CO)

2nd Place – “Typical Section Models for Body Freedom Flutter,” Nicholas Hawley and Samuel Stanton, United States Air Force Academy (Air Force Academy, CO)

3rd Place – “Circular Restricted Three Body Problem for Lunar Position, Navigation, and Timing System,” Kaitlyn Roberts and Lt Col Nathan Collins, United States Air Force Academy (Air Force Academy, CO)

Masters Category

1st Place – “A Multi-Agent UAS Path-finding Algorithm for Unmanned Traffic Management Operations,” Justin Nguyen and Mujahid Abdulrahim, University of Missouri–Kansas City (Kansas City, MO)

2nd Place – “Development of Multi-Mission UAS Design Optimization and Prototyping Architectures,” Austin Stark, Alan Cordon, and Mujahid Abdulrahim, University of Missouri–Kansas City (Kansas City, MO)

3rd Place – “Tip Shape, Height, and Thickness Influences on Nonlinear Acoustic Damping from Baffle Blades,” Joseph Day and J. Matt Quinlan, University of Colorado Colorado Springs (Colorado Springs, CO)

Team Category

1st Place – “Design of Large-Scale 3D Printed Components for UAV Cargo Transport,” Cody Watson, Caroline Dixon, and Nate Kuczun, University of Colorado Boulder (Boulder, CO)

2nd Place – “Open Source Evaluation of the Performance Capabilities of the Chengdu J-20 Fighter Future Propulsion System,” Jacob Ellison, Molly Ellinger, Ryan Chen, Joseph McCaffrey, Gavin Ross, Alicia Kwasny, Saif Dabash, Emily Huber, Shane Lindsay, Isaac Monson, and Connor Wiese, United States Air Force Academy (Air Force Academy, CO)

3rd Place – “CubIST: CubeSat Integrated Star Tracker,” Chesney Boal, Natalie Link, Cameron Humphreys, Chava Friedman, Nicolena Weber, Quaid Garton, Matthew Gedrich, Chad Pflieger, Maria Callas, and Josephine Johnson, University of Colorado Boulder (Boulder, CO)

Region VI Winners

High School Category

1st Place – “Computational Fluid Dynamics For a Solar Car,” Lucien Freemesser and Hai Lin Truman, Raisbeck Aviation High School (Tukwila, WA)

2nd Place Tie – “Creating an Alpha Indicator for a Schweizer 2-33,” Canaan Cortes, Mother of Divine Grace High School (Ojai, CA)

2nd Place Tie – “Synthesis and Applications of Flash Joule Heating Graphene for Manufacturing in Space,” Andrew Lusk and Joseph Whitesell, Calvary Chapel High School (Santa Ana, CA)

Undergraduate Category

1st Place – “Thermal Analysis of Boron/PVDF and Boron Carbide/PVDF Mixtures,” Moussa Coulibaly and Joseph Kalman, California State University, Long Beach (Long Beach, CA)

2nd Place – “Processing of High-Speed Video Data for Rotating Detonation Engines,” David Menn, University of Washington (Seattle, WA)

3rd Place – “An Empirical Study of Baffle Impact on Diffusive Fuel/Oxidizer Mixing with Simulant Gases,” Carter Vu, University of Washington (Seattle, WA)

Masters Category

1st Place – “Modification of Supersonic to Hypersonic Wind Tunnel by Sizing Heater for High Enthalpy Conditions,” Justin Slavick and Nandeesh Hiremath, California Polytechnic State University, San Luis Obispo (San Luis Obispo, CA)

Team Category

1st Place – “Design of a Lunar Architecture for Tree Traversal in Service of Cabled Exploration (LATTICE),” Kaila Comibra, Calle Junker, Lucas Pabarcious, Malcolm Tisdale, Jedidiah Alindogan, Robert Daigle, Nathan Ng, Parul Singh, Tomás Wexler, and Soon-Jo Chung, California Institute of Technology (Pasadena, CA)

2nd Place – “Water Impact of Rigid Biconic Geometries: An Experimental Investigation into Space Capsule Splashdown Events,” Vihan Krishnan, Kirin Peterson, Pinhua Guo, and Mahmood Alfayoumi, University of Southern California (Los Angeles, CA)

3rd Place Tie – “Characterization of Additively Manufactured Fuel Grains for Hybrid Rocket Applications,” Jacob Davies, Lance Mayhue, and Jenna Matus, University of Southern California (Los Angeles, CA)

3rd Place Tie – “Harvesting Thermal Energy from Frictional Braking by using a Thermoelectric Medium,” Victoria Malarczyk, Cade Hermeston, Will Soiland, Joseph Weissig, and Luke Wilson, University of Southern California (Los Angeles, CA)

Obituaries

AIAA Fellow Mellor Died in January

Arthur McLeod (Mac) Mellor, age 80, died 25 January.

Mellor earned a B.S. degree and a Ph.D. in aeronautical engineering from Princeton University. He joined the faculty of Purdue University in the School of Mechanical Engineering where he was promoted to professor in 1975 and served as graduate program administrator. From 1982 to 1987, he was Hess Professor of Combustion in Mechanical Engineering at Drexel University and served for one year as acting department chair. In the 1980s he accepted short appointments in industry and the U.S. Army and Navy.

Mellor joined the faculty of the School of Engineering at Vanderbilt University in January 1988 as Centennial Professor of Mechanical Engineering. He retired in 2004.

During his career, Mellor's research focused on solving difficult problems in gas turbine and rocket propulsion and providing solutions to industry. He developed engineering models to predict engine performance. He was particularly adept at bringing together teams of government, industry, and university researchers. His research achievements were recognized in 2002 when he was elected Fellow of AIAA.

In his years at Vanderbilt, Mellor promoted graduate education, serving twice as director of Graduate Studies in mechanical engineering. He was a strong proponent of undergraduate research and independent study.

Mellor is past member of the NATO/AGARD Propulsion and Energetics Panel. He published more than 150 papers, book chapters and articles, and edited one book, as well as teaching several short courses for government and industry.

Mellor served AIAA in several capacities. He was a member of the AIAA Propellants and Combustion Technical Committee from 1990 to 1996, and he served as chair from 1994 to 1996. He was also a member of the Student Activities Committee (1997–2001) and the Publication Committee (1997–2006).

AIAA Associate Fellow Martin Died in March

Dr. James "Jim" A. Martin died on 11 March. He was 77 years old.

Martin studied aerospace engineering, and earned a B.S. at West Virginia University, M.S. at Massachusetts Institute of Technology, and Ph.D. at George Washington University. For 50 years he solved problems in the field of aerospace engineering at NASA, the University of Alabama, and Boeing. He was constantly learning and educating others on space travel, science, and solutions for climate change.

An AIAA Associate Fellow and a member of AIAA for over 50 years, Martin was very involved with the AIAA Orange County Section. He was section chair from 2020 to 2021 and was most recently program chair. Because of his efforts, the section was honored with 3rd place in the 2021 Outstanding Section Award, Large Section. Martin was also a member of the AIAA Space Transportation Technical Committee (1992–2000), and had been an associate editor of the *Journal of Spacecraft and Rockets* (2004–2012).

AIAA Fellow Green Died in March

Dr. John E. Green, who was responsible for the development of aerodynamics capability at the Royal Aircraft Establishment (RAE) at a critical time for UK aviation and, latterly, explored global aviation's interaction with the environment, died in mid-March.

Green studied engineering at Cambridge University, graduating in 1959. Initially working for the de Havilland Engine company, he returned to Cambridge in 1961 to research the interaction of shock waves and a turbulent boundary layer, gaining his Ph.D. in 1966.

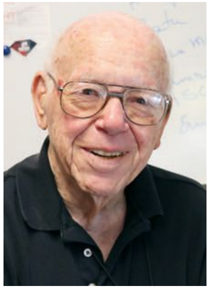
Joining the Aerodynamics Department at the RAE in 1964, he worked on aerofoil design methods. His most notable contribution was "Green's lag entrainment" method for turbulent boundary layer development. He was made Head of the Wind Tunnels Division (Bedford) in 1971, then Head of Propulsion Division, Head of the Noise Division, and finally Head of the Aerodynamics Department in 1978. This period was notable because the RAE was supporting the Concorde flight tests prior to its introduction into service in 1976, while also contributing to the Tornado combat aircraft program.

Green was appointed Director, Project Time and Cost Analysis for the Procurement Executive, Ministry of Defence and in 1984, was posted to the British Embassy in Washington, DC, as the Minister-Counsellor and Deputy Head of British Defence Staff, returning to the UK in 1985 as RAE Deputy Director (Aircraft). His final role was Chief Executive of the Aircraft Research Association, before retiring in 1995.

A member of the Royal Aeronautical Society for over 50 years, Green was its President from 1996 to 1997. He was the Society's representative on the International Council of the Aeronautical Sciences (ICAS) from 1986 to 2000, and ICAS' President from 1996 to 1998. He was awarded the 2006 Maurice Roy Medal. He also had a long association with NATO's Advisory Group for Aerospace Research and Development, serving on both the National Delegates Board and the Fluid Dynamics Panel.

His work on aeronautics and the environment was conducted through the RAeS's Air Travel– Greener-by-Design Group, where he was Chairman of the Design, Science and Technology Sub-Group for over 20 years.

AIAA Fellow Hilton Died in March



Harry H. Hilton died 29 March. He was 95 years old.

Hilton was born in then-Czechoslovakia, but ahead of the German occupation, his family moved first to France and then Morocco before they immigrated to the United States, arriving in January 1941. Hilton quickly learned English and entered an accelerated program at New York University (NYU) in 1943. He served for two years in the U.S. Army during World War II before returning to NYU where he obtained a B.S. in aeronautical engineering in 1947 and an M.S. in compressible aerodynamics in 1949.

Hilton spent a summer at the University of Michigan taking three courses from highly respected professors such as Stephen Timoshenko, before arriving at the University of Illinois at Urbana-Champaign (UIUC) in fall 1949. He had already completed his course work for his Ph.D. when he began his career as full-time instructor of aeronautical engineering and in 1951 he completed his Ph.D. in theoretical and applied mechanics with a mathematics minor.

Hilton became a full professor at UIUC in 1957. He served as associate department head of aerospace engineering, before becoming department head from 1977 to 1985. During the summers of 1989 and 1990, Hilton was an assistant dean in what was then called the College of Engineering. Prior to his retirement in 1990, he taught every undergraduate course in Aerospace Engineering except propulsion. Additionally, he held appointments as A. M. Freudenthal Visiting Professor, Leopold-Franzens-Universität, Innsbruck, Austria, and Charles E. Schmidt Distinguished Visiting Professor, Florida Atlantic University, Boca Raton.

During his retirement, Hilton continued to conduct research and teach a graduate course. A large body of his research was in the area of viscoelasticity, a property in which solid bodies exhibit behaviors, typically associated with liquids. An internationally recognized authority in solid mechanics, viscoelasticity, and aeroviscoelasticity, he published over 500 papers in journals or conference proceedings and 11 book chapters

In addition to being a Fellow of both AIAA and ASC, Hilton received many professional awards including: AIAA Faculty Advisor Award; 2006 AAUP Membership Award; 2000 Association of College Honor Societies Award; and the 2002 and 2004 AIAA Dayton-Cincinnati Aerospace Sciences Symposium Best Paper Awards. In 2020, Hilton received the Vebleo Scientist Award.

Hilton became an AIAA member in 1947. He was a member of the AIAA Structures Technical Committee (1998–2005, 2007–2008) and the AIAA Non-Deterministic Approaches Technical Committee (2007–2011). He also was a dedicated chair of the AIAA Illinois Section from 2000 to 2021.

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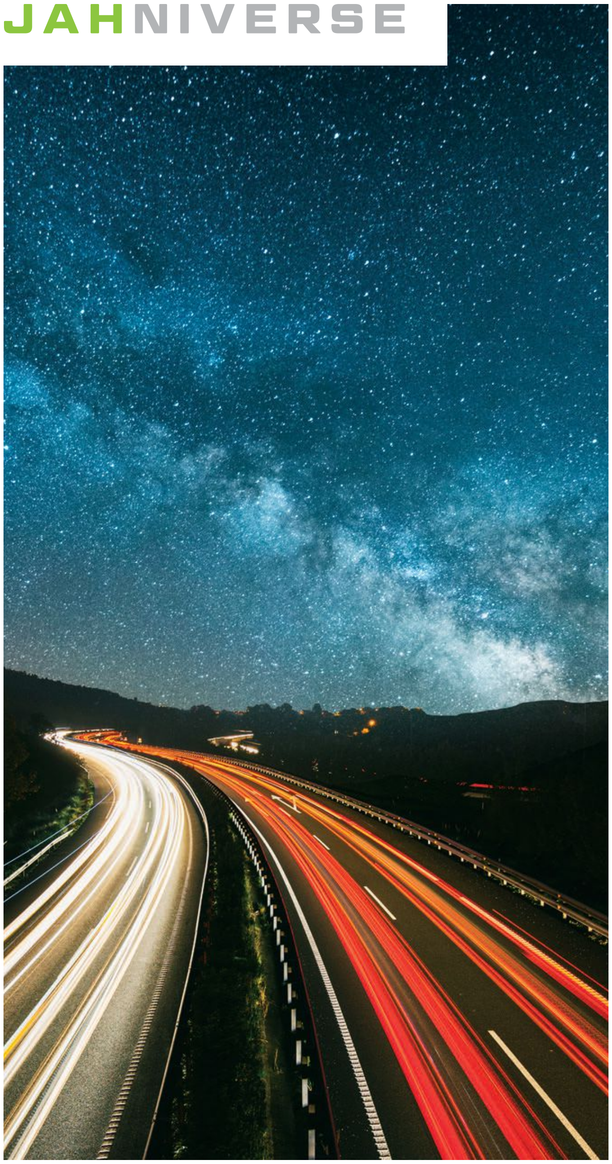

CONTINUED FROM PAGE 64

over the last decade, one group or another has warned of a possible impending collision, while another group has concluded that there was no risk. In such cases, one group's null hypothesis, or default belief, was that a collision is likely and more evidence would be needed to determine this was not the case. On the flip side, the other group's null hypothesis was the opposite.

In cases where a collision did not occur, that does not necessarily mean that a group or agency that discounted the collision risk had adequate evidence to do so. "Absence of evidence is not evidence of absence," according to a line attributed to cosmologist Martin Rees and made famous by Carl Sagan. When two entities have opposing null hypotheses and incomplete evidence, their decisions can also be opposite of each other. This situation introduces otherwise avoidable operational risk and results in operational costs.

The problem of incomplete evidence comes up in other scenarios as well. Intentionally blowing up one of your satellites in space and creating a cloud of space debris can have long-lasting consequences. A satellite operator who loses a spacecraft to a collision with debris and an astronaut who has to defer a critical spacewalk and seek shelter have each experienced what the lawyers call "harmful interference." Such deliberate and irresponsible acts should result in some form of compensation for the victims. However, no single entity has a complete set of data or evidence to prove that such evasive maneuvers were necessary.

Last November, the International Space Station performed a propulsive maneuver to avert the risk of colliding with a piece of debris from an anti-satellite test that China performed in 2007. This maneuver was a unilateral decision based on a perception of impending harm, rather than on a complete set of evidence available to and trusted by all space operators.

Having a pool of multiple independent sources of information available to all space operators would allow them to draw conclusions based on the same body of evidence and then compare notes before expending fuel and time on maneuvers that might themselves invite risk. As long as conclusions are drawn from different evidence, it is impossible to separate real from false alarms. Even if this aggregate pool of evidence fails to meet completeness, actions of operators could at least be coordinated and consistent, leading to improved predictability. That is a goal we must strive to achieve for space safety and long-term sustainability.

United Nations treaties and conventions, such as the 1971 Convention on International Liability for Damage Caused by Space Objects, provide a framework for signatories to raise concerns and make formal complaints about the actions of other governments and the corporations based in their jurisdictions. However, just because a government complains does not guarantee that its concern is quantifiably real or justified. This "you said, I said" environment can lead to undesirable geopolitical escalation between countries.

In December, China raised a complaint in a note verbale, a kind of diplomatic message, to the U.N. secretary general, saying on two occasions it had to maneuver its space station with three taikonauts aboard to avoid risk of colliding with a growing number of SpaceX Starlink satellites. The United States, citing evidence from U.S. Space Command, responded to the U.N. that there was no risk of collision between Starlinks and the Chinese space station in either of these events. Neither party provided evidence that could be scrutinized or combined to draw consistent conclusions. No third party independently confirmed or refuted either side's claims. This lack of common ground won't suffice for a species that intends to peacefully spread its existence into space.

To be sure, having evidence that meets the criteria of being complete may never be obtainable for a large number of potential events in space. However, it is possible for humanity to develop and deploy a framework that provides a widely accessible and curated set of joint, multisource evidence from which all interested parties could draw consistent conclusions. This consistency would be a step toward improving space safety and ensuring the long-term sustainability of the orbital environment for free and unhindered peaceful use of outer space. ★

LOOKING BACK

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1922

May 1 The Soviet-German airline Deutsche-Russische Luftverkehrsgesellschaft begins service between Moscow and Königsberg, with connections to Berlin and other cities, using Fokker F.III monoplanes. Popularly known as Deruluft, the airline was formed in November 1921. **Flight,** May 11, 1922, p. 275; David Baker, **Flight and Flying: A Chronology**, p. 143.

May 5 Germany is given permission by the Allied authorities to resume the design and construction of civil airliners, although under restrictions to prevent their possible military use. David Baker, **Flight and Flying: A Chronology**, p. 143.

May 31 A free balloon using helium is flown for the first time by U.S. Navy Lt. Cmdr. J.P. Norfleet during the National Elimination Balloon Race in Milwaukee, although the balloon does not place. Eugene M. Emme, ed., **Aeronautics and Astronautics 1915-60**, p. 15.

1947

May 19 Air service between Edinburgh and London starts with a daily British European Airways flight. **The Aeroplane**, May 30, 1947, p. 576.

1 **May 22** The U.S. Army test fires a prototype of its first surface-to-surface ballistic-guided missile at White Sands Proving Ground in New Mexico. The 14-meter Corporal E travels 100.6 kilometers and reaches an altitude of 39.4 kilometers. E.M. Emme, ed., **Aeronautics and Astronautics 1915-60**, p. 57; K.W. Gatland, **Development of the Guided Missile**, pp. 153, 256-257.

May 28 At the request of Britain's Ministry of Civil Aviation, British South American Airways starts a series of experimental nonstop refueling flights between London and Bermuda with two Avro Lancaster aircraft. Conducted over the Azores, the refueling tests seek to determine the feasibility of nonstop passenger service over this 5,400-kilometer route. **The Aeroplane**, June 6, 1947, p. 606.

May 30 Herbert Thomas, who in 1910 helped his cousin Sir George White found British and Colonial Aeroplane Co. (later renamed Bristol Aeroplane), dies at age 55. After learning to fly in 1910 at age 18, Thomas became the youngest pilot to hold a license. After World War I, he became a director of Bristol Aircraft, founded Bristol flying schools and from 1933 to 1935 chaired the council of the Society of British Aircraft Constructors. **The Aeroplane**, May 30, 1947, p. 560.

1972

May 1 NASA Ames Research Center's C-8A Buffalo research aircraft completes its first flight from the Boeing Co.'s Seattle plant equipped with a wing planned for short takeoff and landing aircraft. Piloted by Boeing's Thomas E. Edmonds, the aircraft reaches an altitude of 6,500 feet. The primary objectives of the 51-minute flight are evaluating the aircraft's structural integrity and flight characteristics, all of which are met. **Air Force Magazine**, August 1972, p. 46.

May 1 NASA's Marshall Space Flight Center in Alabama announces its completion of the largest solar cell arrays ever devised for spacecraft. The two arrays have a combined surface area of 236 square meters and will power electric systems of the Orbital Workshop, Apollo Telescope Mount and other major components of NASA's Skylab space station launched in 1973. Each array provides 10,500 watts of power, twice the average level needed for a three-bedroom house. **Marshall Space Flight Center Release** 72-54.

May 8 Swiss federal aircraft workers in the village of Emmen report that they have developed a hot water rocket for assisted aircraft takeoffs. Known as a pulsated overheated water rocket, the technology has been tested on Swiss Air Force Dassault-Breguet Mirage 3 and Pilatus Porter aircraft. **Aviation Week**, May 8, 1972, p. 9.

2 **May 10-24** Images from NASA's Mariner 9 orbiter provide the first direct evidence of water ice on Mars, Jet Propulsion Laboratory scientist James A. Cutts announces during the 15th meeting of the Committee on Space Research, held in Madrid. **Washington Post**, May 23, 1972, p. A10.

3 **May 16** A collection of 28 paintings by artist and architect Chesley Bonestell and three original drawings by Wernher von Braun are placed on exhibit at the American Museum of Natural History in New York City for an indefinite period. The Bonestell paintings, created in the early 1950s, depict future space explorations, and the von Braun drawings are of suggested spacesuits for extravehicular activities on the moon. NASA, **Astronautics and Aeronautics, 1972**, p. 185.

May 17-19 Bell Helicopter chairman Edwin J. Ducayet is awarded the Dr. Alexander Klemin Award during the 28th Annual National V/STOL Forum held in Washington, D.C., for his "notable achievements in the advancements of rotary wing aeronautics." **Aviation Week**, May 22, 1972, p. 9.

May 19 The Soviet Union launches its Molniya II-2 communications satellite from the Plesetsk Cosmodrome to maintain long-distance telephone and telegraph radio communications as well as to relay Central Television Service programs to stations in the Orbita network. NASA, **Astronautics and Aeronautics, 1972**, p. 188.

May 22 Apollo 7 astronaut Donn F. Eisele is sworn in as director of the Peace Corps in Thailand. He supervises 315 volunteers and 14 paid staff members in Bangkok. **New York Times**, May 23, 1972, p. 27.

4 **May 24** U.S. President Richard Nixon and Soviet Union Premier Aleksey N. Kosygin sign the Agreement Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes in Moscow. Among other projects, this agreement leads to the 1975 Apollo-Soyuz Test Project in which a U.S. Apollo spacecraft docked with a Soviet Union Soyuz capsule. The project and its memorable handshake in space is a symbol of détente between the two superpowers during the Cold War and marks the end of the space race that began with the 1957 launch of Sputnik 1. NASA, **Astronautics and Aeronautics, 1972**, pp. 195-199.

May 25 NASA's Pioneer 10 probe crosses the orbit of Mars en route to Jupiter. The spacecraft has traveled 75 million kilometers from Earth since its launch in March and is scheduled to enter the asteroid belt in early July. **NASA Release** 72-111.

May 26 NASA announces the retirement of Wernher von Braun, deputy associate administrator for planning, effective July 1. Born in Germany, von Braun during World War II became technical director of the V-2, the world's first large-scale liquid propellant rocket. In 1945, following his surrender to the Allies, he came to the U.S. to direct the U.S. Army's high-altitude firings of captured V-2 rockets. He later became director of NASA's Marshall Space Flight Center and the chief architect of the Saturn V launch vehicle that launched astronauts toward the moon. NASA, **Astronautics and Aeronautics, 1972**, pp. 202-203, 205-206.

1997

5 **May 5** A Delta II launches the first five Iridium satellites into low-Earth orbit from Vandenberg Air Force Base, California. The satellites, built by Motorola, are the first of a planned network of 66, plus seven backups, designed to provide the

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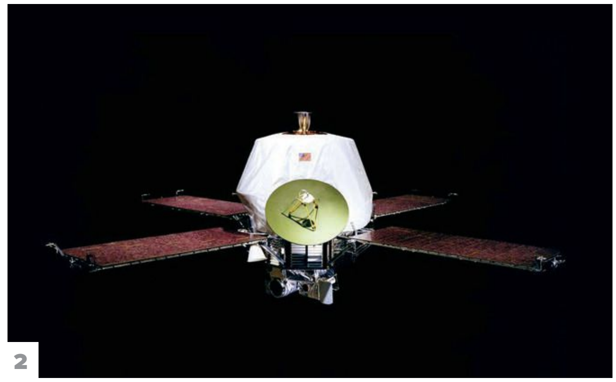

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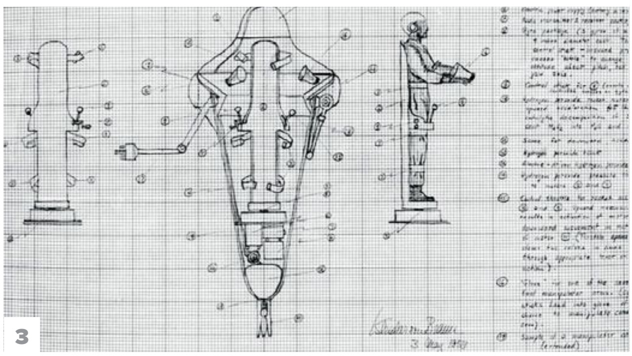

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first satellite-to-ground mobile telephone, email and other communication links worldwide. **Space News**, May 12-18, 1997, p. 22.

6 **May 15** The space shuttle Atlantis launches from NASA's Kennedy Space Center in Florida on flight STS-84. Commanded by Charles J. Precourt and piloted by Eileen M. Collins, the flight carries seven crew members, including cosmonaut Elena V. Kondakova, to the Mir orbiting laboratory. NASA **Astronautics and Aeronautics: A Chronology, 1996-2000**, p. 72.

7 **May 17** The NASA-McDonnell Douglas X-36 tailless drone makes its first flight. The aircraft is powered by a Williams F112 turbofan engine with 700 pounds of thrust. **Aviation Week**, May 26, 1997, p. 21.

May 23 The Aster anti-missile missile intercepts an anti-ship missile in a test of the design's guidance system, prompting interest from countries including France, Italy, Saudi Arabia and the United Kingdom. Specifically, France plans to add the missiles to its Charles de Gaulle aircraft carrier and Horizon frigates. **Aviation Week**, Sept. 15, 1997, pp. 40-41.

May 25 On the 36th anniversary of President John F. Kennedy's call for the United States to dedicate itself to landing astronauts on the moon and returning them safely to Earth, the nation celebrates the first National Space Day to recognize past achievements and inspire future endeavors. NASA **Astronautics and Aeronautics: A Chronology, 1996-2000**, p. 74.

The missing ingredient for assigning fault in space

BY MORIBA JAH | moriba@utexas.edu

If a driver were to veer from the street and drive into me while I'm running in my neighborhood, that person — and possibly the person's employer — could be held financially or even criminally liable by a court for injuring me, regardless of intention.

The caveat is that in order to win, I must prove cause and effect, and for that I need evidence that's complete enough to meet the standard of doubt required by the court.

Assume that witnesses saw the driver look at a cellphone (which I've personally witnessed while running) and then veer. Cellphone text records then show that the driver was actively texting at the time. For this evidence to be complete, two criteria must be met: (a) Deduction is possible — the driver was looking down at the cellphone, and this avoidable distraction caused the driver to lose focus and hit me. The driver should not have been operating a motor vehicle while texting. And (b) no evidence refutes this conclusion — witnesses did not report seeing a child chasing a ball toward the car or a baby carriage rolling away from a parent or anything that would justify the driver veering into me on the sidewalk.

Unfortunately, for events in near-Earth orbit, we're still quite far from the ability to attribute fault as efficiently as we can on land, not because we lack legal instruments to make claims but because by and large, we lack evidence that is complete.

Incomplete evidence can lead to chaos and confusion in outer space. When a space traffic information provider or satellite operator sounds the alarm about a potential on-orbit collision, we can't blindly trust them and act on their data, assuming this to be truth. Maneuvering to get out of the way of a fictitious event may actually put the satellite into harm's way instead.

Conflicting evidence is a problem in determining real from false alarms. At least several times

CONTINUED ON PAGE 61

Moriba Jah is an astrodynamicist, space environmentalist and associate professor of aerospace engineering and engineering mechanics at the University of Texas at Austin. An AIAA fellow, he's also chief scientist of startup Privateer and hosts the monthly webcast "Moriba's Vox Populi" on SpaceWatch.global.