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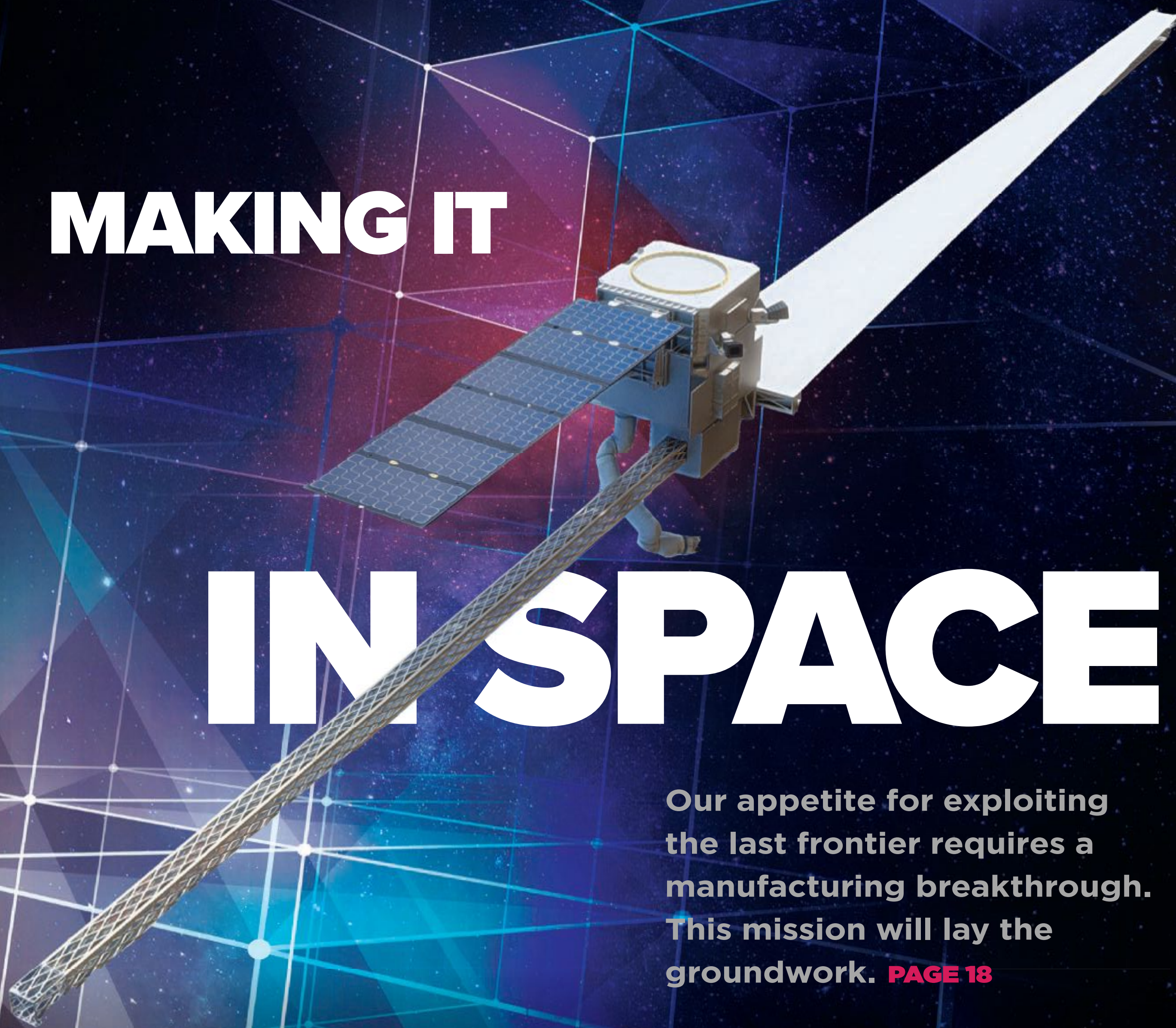
MAKING IT IN SPACE



Our appetite for exploiting the last frontier requires a manufacturing breakthrough. This mission will lay the groundwork. PAGE 18

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AIAA
SHAPING THE FUTURE OF AEROSPACE

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Above: NASA astronaut Barry "Butch" Wilmore shows a science sample container that was additively manufactured on the International Space Station. NASA

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EDITOR-IN-CHIEF
Ben Iannotta
beni@aiaa.org

ASSOCIATE EDITOR
Karen Small
karens@aiaa.org

STAFF REPORTER
Cat Hofacker
catherineh@aiaa.org

EDITOR, AIAA BULLETIN
Christine Williams
christinew@aiaa.org

CONTRIBUTING WRITERS
Adam Hadhazy, Moriba Jah,
Robert van der Linden, Amanda Miller,
Frank H. Winter

Basil Hassan **AIAA PRESIDENT**
Daniel L. Dumbacher **PUBLISHER**
Rodger Williams **DEPUTY PUBLISHER**

ADVERTISING
advertising@aiaa.org

ART DIRECTION AND DESIGN
THOR Design Studio | thor.design

MANUFACTURING AND DISTRIBUTION
Association Vision | associationvision.com

LETTERS
letters@aerospaceamerica.org

CORRESPONDENCE
Ben Iannotta, beni@aiaa.org

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Before becoming an associate professor at the University of Texas at Austin, Moriba helped navigate the Mars Odyssey spacecraft and the Mars Reconnaissance Orbiter from NASA's Jet Propulsion Lab and worked on space situational awareness issues with the U.S. Air Force Research Laboratory.
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Amanda Miller
Amanda is a freelance reporter and editor based near Denver with 20 years of experience at weekly and daily publications.
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DEPARTMENTS

EDITOR'S NOTEBOOK | SUSTAINABILITY

Fresh energy for decarbonization

The United States government at the moment is giving no hints that it is ready for the dramatic shift that's afoot on the issue of decarbonizing the air transportation sector. If the wheels are already turning internally on this problem in the Biden administration, that's good, because the latest climate science looks dire. See for example, "Rate of mass loss from the Greenland Ice Sheet will exceed Holocene values this century," in the journal Nature's October 2020 issue.

Simply put, no sector can be given a pass under the Biden administration's pledge to create a net-zero economy by 2050, and increasingly, the industry doesn't seem to want one.

To sense the shift that's underway, consider that the air transportation industry's position has long been that the best it could do globally was a 50% reduction in net carbon output by 2050, the Paris Agreement's point of no return for damaging climate impacts. Regionally, however, airlines, airports and industry groups are starting to embrace the more aggressive goal, just as the industry's Air Transportation Action Group last year predicted would happen. The European sector in February announced that it will target net-zero emissions by 2050 for flights departing from the European Union, plus Iceland, Liechtenstein, Norway, Switzerland and the U.K. At least 20 airlines, including American and United, are now targeting net-zero by 2050.

In this issue, we provide some valuable but initial insights about how to achieve this more ambitious goal. The opinion piece on Page 40, "Decarbonizing by 2050: Optimists, pessimists and realists," assesses the technologies that researchers and planners must either master or perhaps set aside, and quickly, if they are to meet aggressive decarbonization goals. Our story on Page 9, "From food to jet fuel," provides an example of the kind of breakthroughs that will be needed. The Flight Path column, "Our role in assuring a cleaner, greener future," emphasizes that AIAA stands ready to help.

Of course, the technical brainstorming will be the fun part. Figuring out how to fund the required breakthroughs will be less so. Should NASA's Aeronautics Research Mission Directorate become the focal point for American contributions to the international collaboration that will be required? That sounds logical, but right now this directorate, the first A in NASA, comprises 3.5% of NASA's $23 billion annual budget. Those with the other 96.5% are presumably fond of their missions too. Nevertheless, we'll soon find out if a dramatic shift is at hand when the Biden administration unveils its fiscal 2022 budget request. Such a shift would seem to require digging into funding for human spaceflight and space science and technology in ways that would be painful and maybe even politically untenable.

So what to do? Research contributions are likely to be made by corporations through their internal research and development dollars, and by the Energy Department and FAA. What's needed, though, is a systems approach that ties together transformative designs, propulsion and energy, fuels and ground infrastructure. The agency born from the National Advisory Committee for Aeronautics seems like the best one to do that.

No matter what the Biden administration has in store, I'm mindful that our future can't rest entirely on political leadership. Problems like this one will test us all, from the media, to the halls of governments, to the nonprofit and profit worlds to academia. ★

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

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FLIGHT PATH

Our Role in Assuring a Cleaner, Greener Future

The aviation community plays a vital role in addressing the challenges of climate change. While the industry has made progress toward reducing carbon emissions, much work remains. Reaching net zero carbon emissions by 2050 requires the ultimate sense of urgency – it's only 30 years into the future. What meaningful steps have we made toward reaching this goal already? As we recognize Earth Day this month, what do we need to do to ensure we are leaving Mother Earth as healthy as possible for the next generation?

Industries, government, and academia must collaborate in setting forth, investing in, and achieving sustainability goals that will propel our nation and the world into a cleaner and greener future. We must explore all categories of sustainability – human, social, economic, and environmental – as they intersect our industry.

AIAA believes it is imperative to convene key stakeholders who must swiftly develop new technologies to assure our environmental, economic, and social needs, allowing prosperity for now and future generations. We highlight the latest advancements in these new technologies, advocate for R&D funding, help prepare the workforce, and support policymakers. In just the first few months of this year, we have heard from several AIAA corporate members looking ahead at both near-term and long-term needs.

At the 2021 AIAA SciTech Forum, Christopher Raymond, Boeing's first Chief Sustainability Officer addressed sustainability in the context of the aviation industry's recovery from the pandemic. Bouncing back will require "all the innovation that we can muster, and a lot of that innovation will be around sustainability." He was optimistic that renewing the airline fleets and scaling up sustainable aviation fuel (SAF) production in the next 10 years would be important steps toward returning to growth, holding carbon emissions neutral, and then starting to reduce them.

In February, AIAA facilitated collaboration on sustainability with an industry stakeholder webinar, "Sustainability in Flight: Our Journey to Decarbonization." The panel discussed current efforts and the significant cooperation, innovation, and education required for the aviation industry to reduce its carbon footprint.

Amanda Simpson, Vice President of Research and Technology for Airbus Americas, noted that "society is demanding" sustainability. She encouraged a push for government action supporting hydrogen production. "Let the government fund or mandate the development of hydrogen production to the same extent right now that they're doing for petroleum production."

Bruce Holmes, Alakai Technologies' former Chief Technology Officer, agreed, "We'd like to see that happen." He encouraged AIAA and other technical professional societies to advocate for this and believes the energy industries would join the effort.

Arjan Hegeman, General Manager of Advanced Technologies for GE Aviation, added, "[It requires] all the elements – it's SAF, it's hydrogen, and it's overall aircraft fuel propulsion efficiencies. We should partner with the government and figure out how we can accelerate all those paths." The panel affirmed the government can play a large role at the federal, state, and local levels.

AIAA members took the message of prioritizing sustainability to Capitol Hill during the 2021 Congressional Visits Day. State teams from across the country met with lawmakers and their legislative staff, building relationships and engaging in a dialogue on key issues of importance to the aerospace community. Several congressional offices are looking to AIAA for additional educational resources.

The discussion on the government's role in furthering sustainability will continue Monday, 26 April, in a policy-focused webinar featuring representatives from the FAA, NASA Aeronautics Research Mission Directorate, and the U.S. House Subcommittee on Space and Aeronautics. This discussion will explore the Biden Administration's priorities, the role of Congress in creating incentives for technology development, NASA's vision to advance the newest R&D to achieve our low carbon future, and needed regulations and international collaboration to be led by the FAA. We hope you will join us.

AIAA also recently published an information paper that highlights the challenges to aviation systems when transitioning from oil to new energy sources. The paper lists the needed steps for the community to reach carbon neutrality by 2050, including government support; deployment of SAF for current airline fleets; adoption of hydrogen fuel cells and other clean, renewable energy sources; focus on achieving new solutions by researchers; and development of the workforce in the vital technical disciplines.

We need to take all of these steps – advance new technologies, secure necessary funding for R&D, ensure workforce readiness, and gain the support of policymakers – to reach this bold goal. AIAA is committed to ongoing advocacy for these efforts. We also will build upon our momentum throughout this year during AIAA forums and other events. Outcomes from these events will help drive the much-needed progress.

Join us in the important work to reach carbon net zero by 2050. Together we can turn up the volume, assure our human future, and make the changes our home planet deserves. ★

Dan Dumbacher
Executive Director, AIAA

- **READ** "Decarbonizing by 2050: Optimists, pessimists and realists," page 40.
- **REGISTER** at aiaa.org for the upcoming webinar, "Sustainability in Flight – The Government's Role in Achieving Decarbonization."
- **DOWNLOAD** the information paper, "Sustainability in Flight: Our Journey to Decarbonization," at aiaa.org/advocacy/Policy-Papers.
- **LEARN** the history and current developments with the on-demand short course, Sustainable Aviation (learning.aiaa.org).

AERO PUZZLER

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

Plenty of hot air

Q. Our fictional slugger who fell just a vote short of the Hall of Fame was once asked to ruminate about the physics of the long ball: "Well, just like saltwater is denser than freshwater, cold air is denser than warm air. We all know it's easier to swim in saltwater, and it's kind of like that with a baseball in the cold air. You hit it out toward the fence and let it swim on a cushion of cold air right into the stands. I never believed that the ball carries better on hot days, even if the humidity gives some lift. Those were my days off." Was our slugger on his physics game or did he miss his chance at the Hall of Fame?

Draft a response of no more than 250 words and email it by noon Eastern April 12 to aeropuzzler@aiaa.org for a chance to have it published in the May issue.

FROM THE FEBRUARY/MARCH ISSUE

RIGHT STUFF FOR WRIGHT BROTHERS: We asked you why the Wright brothers would be interested in talking to Bob Gilruth in Langley, Virginia, in 1941.

WINNER: In 1941 Gilruth was working for NACA at Langley, where he performed flight research. His research led to NACA Report R755, Requirements for Satisfactory Flying Qualities of an Airplane, published in 1941, in which he defined a set of requirements for the handling characteristics of an aircraft. Until this point, no set of guidelines for pilots and aircraft designers existed. In an interview [for an oral history project at the National Air and Space Museum], he explained: "Of course the way you define it is, you have to be not only able to go to the extremes of the envelope of flight, but you have to be able to do it with precision. You have to be able to make that airplane go exactly the way you want it, point the way you want, which means you've got to have not only the ability to go to the boundaries of the envelope, but go there with precision. To do it just the way you want it, that means a very high degree of control, and in order to get that you have to have the right kind of force per g and the right kind of variation of parameters, which is what I tried to put into my requirements." The Wright brothers, never having taken flight and having no idea what to expect, took flight to find out in a few desperate minutes if they could fly. As they sat in the seat thinking through the controls for their first flight, the data from Gilruth would have been invaluable.

Kevin Burns, AIAA associate fellow
San Diego
kevinrobbburns@gmail.com

For a head start ... find the AeroPuzzler online on the first of each month at https://aerospaceamerica.aiaa.org/ and on Twitter @AeroAmMag.

From food to jet fuel

BY CAT HOFACKER | catherineh@aiaa.org

▲ **A new sustainable aviation fuel** produced by the U.S. National Renewable Energy Lab in Colorado starts off as wet waste, including food scraps that are fermented in a metal reactor tank, at right. Dennis Schroeder / NREL

Researchers at a U.S. Energy Department laboratory in Colorado want to turn your table scraps into jet fuel.

Their early findings indicate that wet waste including food fragments and animal manure can indeed be converted into SAF, sustainable aviation fuel. Today's SAFs are derived from sources including cooking and other oils and blended with conventional jet fuel. New sources are needed if the air transport industry is to meet its long-standing goal of reducing carbon emissions by at least 50% of 2005 levels by 2050.

"In the U.S. alone, we use well over 20 billion gallons per year in jet fuel, so there's no way that just waste fats, oils and grease can cover that demand," says Derek Vardon, senior researcher at the National Renewable Energy Laboratory based in Golden.

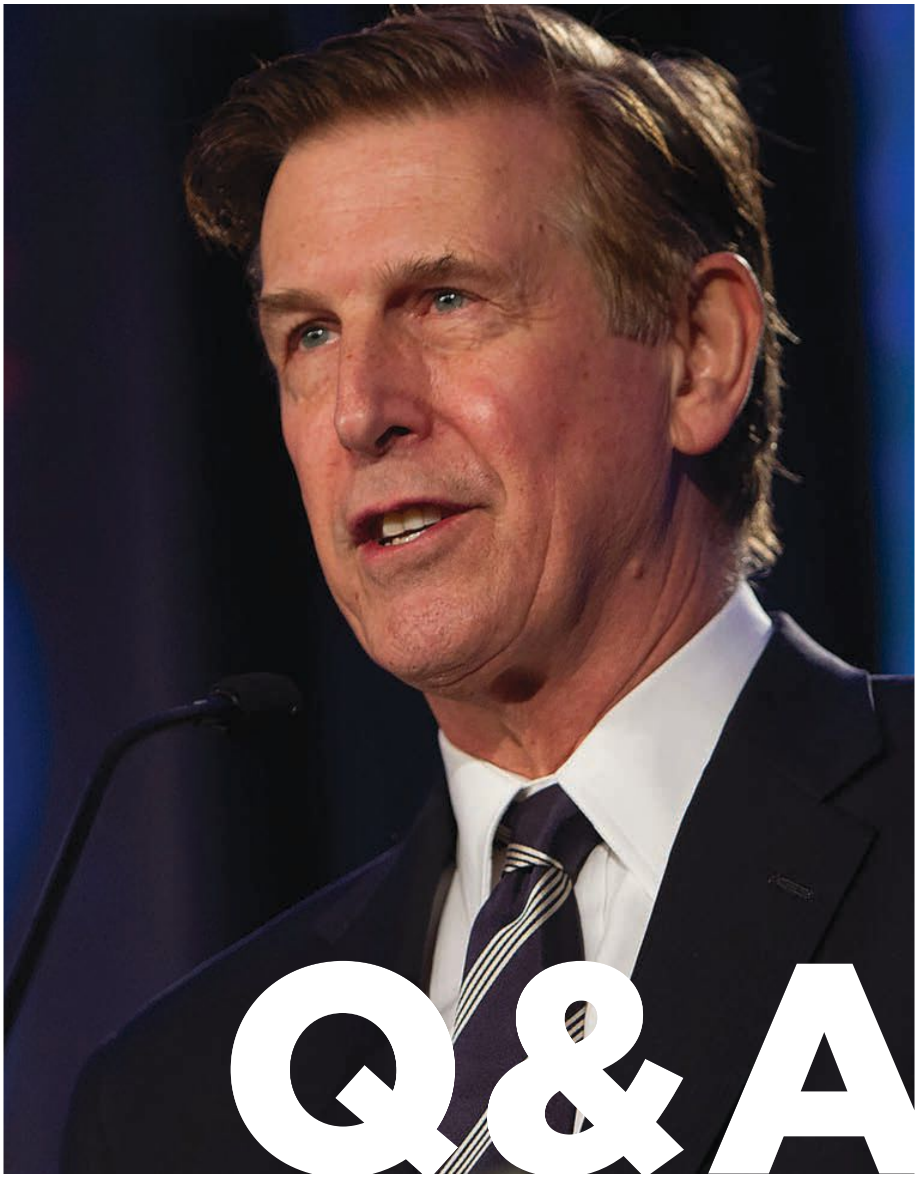
The researchers describe the refinement process for their SAF in a March issue of the journal Proceedings of the National Academy of Sciences. They begin by packing the waste into a sealed reactor tank devoid of oxygen. There, bacteria break down the waste, fermenting it into what Vardon describes as a "neat, stinky liquid" filled with volatile fatty acids. These VFAs are then poured through a stainless-steel tube packed with crushed zirconium oxide, which catalyzes a reaction that turns the VFAs into water and shorter strings of ketones, a class of carbon compound. The ketones then flow through another tube, this one filled with hydrogen gas and crushed platinum-loaded aluminum oxide. The hydrogen reacts with the oxygen in the ketones, the final products of which are water and hydrocarbons.

Last March, the Colorado researchers sent the first fuel samples to colleagues at the University of Dayton in Ohio for analysis. Among the series of tests, they chilled the fuel until it became solid to determine its freezing point, which can't be above minus 40 degrees Celsius for Jet A, according to ASTM International, the standards organization based in Pennsylvania. Alternative fuels must be similar enough to traditional jet fuel that today's aircraft engines would require no modification.

The researchers finalized the SAF formula in September and are now focusing on scaling up production. They want to produce at least 100 gallons (378.5 liters) of fuel, the minimum amount required to begin approving the SAF for commercial use under the Fast Track option offered by ASTM. Under this streamlined process established last year, certain SAFs could be cleared for blending up to 10% volume with traditional jet fuel in one to two years, compared to the long-standing three- to seven-year screening process for SAFs that are approved for 50/50 blends.

"Being able to make a fuel that can get qualified so quickly, not only is it great for getting into the marketplace, but it totally changes the commercialization plan you could have around making low-carbon-footprint, sustainable aviation fuel," Vardon said.

In parallel, the researchers continue to refine a different variant of wet waste-derived SAF that could be blended with traditional jet fuel at higher percentages. ★



American Federation of Government Employees

Aerospace arbiter

U.S. Rep. Don Beyer, D-Va., begins his tenure as chair of the House Subcommittee on Space and Aeronautics with a core belief that aviation and space research should be a "sustained, increased priority" for the United States. In his subcommittee's work of authorizing programs and recommending funds for NASA, he hopes to boost funding for research on new aircraft designs and propulsion technologies that could help reduce the levels of carbon dioxide emitted by today's aircraft. At the same time, Beyer also supports NASA's multibillion-dollar goal of returning astronauts to the moon under the Artemis program. He knows there are difficult choices ahead, and he is fond of paraphrasing John F. Kennedy's maxim about choosing. I called Beyer at his Washington, D.C., office in February to gauge how the competing aeronautics and space goals might be balanced. — *Cat Hofacker*

DON BEYER

POSITIONS: Since February, chair of the House Science Committee's Subcommittee on Space and Aeronautics that authorizes and oversees NASA, the National Space Council and FAA's aerospace R&D programs; member of the House Science Committee since 2015; member of the U.S. House representing Virginia's 8th congressional district since 2015; lieutenant governor of Virginia, 1990-1998.

NOTABLE: Introduced the Cleaner, Quieter Airplanes Act in 2019, which would have required commercial airliners to reduce their greenhouse gas emissions by 50% below 2019 levels by 2040; co-sponsor of the National Aviation Preparedness Plan Act, introduced in February, which would require the Transportation Department and other agencies to work with U.S. airlines, pilot unions and other groups to formulate an action plan to reduce transmission in the event of future disease outbreaks; co-owner of the Beyer Auto Group from 1986 to 2019, when he sold his stake in the collection of Northern Virginia dealerships.

AGE: 70

RESIDENCE: Alexandria, Virginia

EDUCATION: Bachelor of Arts in economics, Williams College, 1972

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NASA's biggest role

We have lots of competing demands — all you have to do is read our arguments for the big covid relief bill the House passed on Feb. 27 at 2 a.m. — but we also have to take the middle-term and the long-term view. Even if it takes us another year or so to catch up with where we were before, the economic outlook for the next 10 years, 20 years is pretty darn good. One of the reasons why I say that is because of America's commitment to science, and probably nothing excites our scientific imagination as much as NASA's missions. If we want our young people to be studying math, physics, engineering, there needs to be some stimulation of the spirit that drives that. Just imagine what the Perseverance rover landing did to people who are thinking about what they want to study in college or graduate school. And when we get the James Webb Space Telescope up and learn much more about the early universe, that should attract a lot of people to physics and philosophy. And then when the Mars Sample Return comes back with signs of life on Mars, just think what that's going to do for biology and philosophy and religion. As humanity, we always have to be thinking about the future in big, bold ways.

Big-ticket items

I'd love to see us reauthorize NASA at higher funding levels. I certainly would love to see the budget increasing at least as quickly as our economy increases. And then within the NASA budget, we're probably two or three months away from NASA's completing the review on the timeline for returning humans to the moon. When we hear about that, whether it's 2024 or 2026 or 2028, there will probably be accompanying budget numbers with it, requirements to make that happen. I'm also very excited about getting the James Webb Space Telescope up in the air. I think that will be just fascinating, the explosion of data compared to Hubble. All the aeronautics research is really important too, including the supersonic flights.

Moon landing

I would love to do it in 2024 if we still can, but we also have to look at what the cost-benefit analysis is. It's the old John Kennedy line that "to govern is to choose." If NASA comes back and says, "we can still do it, but we need a 50% increase in our budget," probably not going to happen. So what can they do with a 10% increase, for instance? I'm sure they're going to come back and present the costs for different dates, and then the policymakers starting with the president will make that decision.

Funding decarbonization

I don't think it's plausible or probably historically accurate to expect the commercial aviation industry to develop all the technologies needed to reduce its carbon footprint without government help, because that's typically not the way we've done it. Some funds come through the defense budget, some through NASA, some through NOAA. It's going to be a mix of taxpayer dollars and private funds, but I don't know what the percentage will be. Now that the House has sent the big covid relief package over to the Senate, our next big project is going to be the infrastructure bill. Everyone on the Democratic side expects that the leading objectives in the infrastructure bill are going to be climate related, which will include everything from electric vehicle tax credits for trucks, buses, cars, but then also looking at ways to stimulate the private sector and aeronautics industry to be really committed to low carbon, zero carbon.

Competing priorities

One of the challenges, not just for me but for all of us on the subcommittee, is balancing the different missions that NASA has: deep space, moon to Mars, Mars Sample Return, aeronautics and planetary science. The biggest thing is to start at the top line. If we keep the NASA budget the same or decreased, we make it

I'd love to see us reauthorize NASA at higher funding levels. I certainly would love to see the budget increasing at least as quickly as our economy increases. And then within the NASA budget, we're probably two or three months away from NASA's completing the review on the timeline for returning humans to the moon.

much harder to find that balance. Instead, if we can increase it by 3% or by 5% or by 6%, then all of a sudden there's a lot more latitude. It's easier to find a balance that everybody's happy with. I would say we need to boost the budget for NASA's aeronautics division. It is critically important, especially when you consider the percentage of overall greenhouse gas emissions that are tied to aviation. Also, the climate parts of the planetary science at NASA should definitely be emphasized. I don't want to make a commitment on the dollars because I don't know what they need, what the proposals will be.

Legacy of the Webb telescope

One of the most painful science hearings that I've been a part of was in 2018 when the House Science Committee brought in Northrop Grumman CEO Wes Bush and hammered him for two hours about the Webb telescope, how it's orders of magnitude more expensive and dozens of years past due.

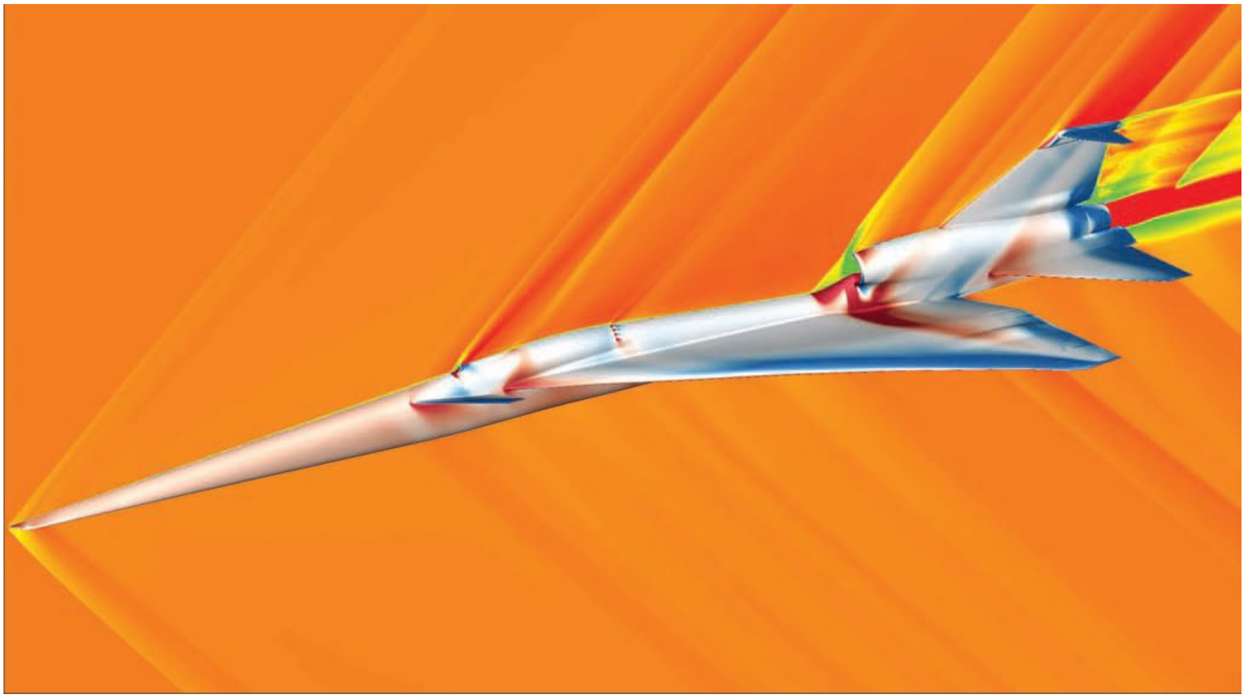
> If the telescope launches in October as planned, it'll arrive in space 14 years behind the originally scheduled date. — *CH*

The two basic defenses were No. 1, we're asking to do way, way more than we were when we first imagined Webb. And then No. 2, we've never built a telescope like this before. We were just guessing, and we guessed really wrong. But if I'm my conservative, fiscally careful Republican pal, when we go to do the next telescope, they're going to have to be asking questions based on the James Webb experience. It's going to be a hurdle to overcome, and the best way to overcome it is by being as honest, accurate, authentic as we can on how much it's going to cost, how long it's going to take and what it's going to do. Let's try to learn from the mistakes we've made in the past, but those mistakes are definitely not a reason not to build those future telescopes, including the Nancy Grace Roman Space Telescope.

Softening support for Space Launch System

I do foresee the day NASA might not own its own rocket. I'm not arguing that we abandon the Space Launch System right now, but I think we need to keep an open mind on whether the NASA investment through the defense industrial base is always going to be the right way to develop our deep space rockets. If the private sector can do it as well and is less expensive, I think we need to be open to that. What's been the downside of having Northrop Grumman and SpaceX deliver supplies or now human beings to the space station? I don't think there's any. But we'd have to be able to say, "Can

▲ **Technicians stack** components of two solid rocket boosters for a Space Launch System rocket at NASA's Kennedy Space Center in Florida, in preparation for an uncrewed launch of an SLS and Orion capsule later this year. "I want SLS to be successful," Beyer says, but the U.S. government should "keep an open mind" about how future deep space rockets are developed.
NASA



the private sector yet deliver a rocket that can do what we've asked SLS to do?" That has to be an ongoing question. I want SLS to be successful — we've invested so much in it — but we always need to be sensitive of the trade-offs, the choices that can be made.

Hurdles to working with China

NASA is moving from the only game in town to a partner, a facilitator, and sometimes even a strategic competitor with the U.S. private sector, which is good. We generally all get better when we compete a little bit and we partner where we can and compete where we can. It's not all that different from how I think the U.S. has to be looking at space competitors around the world: the Indias and United Arab Emirates and Chinas and Russias. I would love to find a way to move in the direction of working with China in space, but not at the expense of ignoring their human rights violations. Unfortunately, international affairs — Uyghur concentration camps, Hong Kong, China cheating on trade deals — makes it harder, but we need to stay at it. We have to find ways to do our very best to hold them accountable for the human rights abuses, for not playing fair in international trading, but at the same time, cooperate with them, partner with them when we can.

National Space Council

I have no objection to the space council. Putting more éminence grise, wise, seasoned people of good intention across the political spectrum in a room to help guide the decisions, means we're going to make better decisions. The better-run companies have good boards of directors that are independent and thoughtful and will challenge the leader. To the extent that the space council contributes to that kind of wisdom, we should preserve it and make sure it's strong and functional. On the other hand, we got by for the previous many decades without them, so we certainly can survive, but I do think we would potentially miss that extra layer of reflection, challenge, wisdom. If I were the chief technology officer, chief science adviser to the president or the head of NASA, I would want to welcome an independent group of people who were giving me the very best advice on how to proceed. How do you find that right balance of aeronautics and Earth science and deep space and moon to Mars? — that's someplace where a space council could be very helpful. ★

▲ **NASA's X-59** Quiet SuperSonic Technology aircraft is one of the aeronautical research projects that Beyer's subcommittee oversees. NASA and Lockheed Martin, the X-59 contractor, are building a database of computational fluid dynamics simulations while the supersonic aircraft is being built.
NASA

Building a new astronomy tool

X-rays emitted by black holes, quasars and other features in deep space have a story to tell, but astronomers have yet to fully tune in by examining the polarization of the beams. Amanda Miller tells the story of a space observatory that could do just that after its launch later this year.

BY AMANDA MILLER | agmiller@outlook.com

The Imaging X-ray Polarimetry Explorer will be an odd-looking astronomy spacecraft when it reaches Earth orbit and morphs into its final form. Three cylindrical telescopes perched at the end of a 4-meter-long extendable boom must reflect X-rays from the cosmos to detectors on the main spacecraft to turn photons into images and measurements.

The design is unusual for a space telescope, and so is the story of how NASA, the Italian Space Agency and contractor Ball Aerospace have arrived at the pre-launch testing phase of what will be the first space observatory dedicated exclusively to X-ray polarimetry, the art of measuring the orientation of energy oscillating within incoming light beams.

First, though, to visualize polarimetry, imagine you could see X-rays coming straight toward you. If they were polarized, you'd see the energy oscillating on the same plane in contrast to unpolarized X-rays, in which the energy would be oscillating on multiple planes. The orientation of this plane is the direction of polarization, and it could be vertical, horizontal, or anything in between. IXPE must measure this direction of polarization, and it will do so by absorbing the X-rays in a gas and imaging the tracks of electrons that are expelled when those gas molecules absorb photons. By gathering many of these electron tracks, the scientists will attempt to statistically determine the direction of polarization for a region of the sky and create images of cosmic features based on where the tracks start.

The resulting cosmic maps should provide clues about the kinds of cosmic structures or phenomena that produced the polarization characteristics.

Overall, X-ray polarimetry could add a new tool in astronomy's long-standing effort to compensate for our inherently one-sided view of the cosmos. Telescopes soak up radiation in a host of wavelengths as it arrives from deep space. "We can reconstruct what we think something looks like in three dimensions even though we don't see in three dimensions," says astrophysicist Martin Weisskopf of NASA's Marshall Space Flight Center in Alabama and IXPE's principal investigator.

For five decades, Weisskopf has dreamed of adding X-polarimetry to that mix, or simply put, "data that has never been taken before."

Creating a spacecraft to do that required devising a method for precisely aligning the telescopes with the detectors, creating the most sensitive X-ray detectors yet, and weathering two surprising programmatic twists.

Launch vehicle surprise

Initially, the IXPE team assumed that their spacecraft would need to fit inside a bargain-priced, air-launched Pegasus XL launch vehicle. After all, NASA had selected IXPE in January 2017 as the next in its line of Small Explorer missions whose budgets are capped at $200 million. IXPE's estimated program cost came in at $188 million, including the launch, the contract with Ball Aerospace, and two years of operating the observatory at the Laboratory for Atmospheric and Space Physics in Colorado.

The Pegasus XL drove the design work throughout Ball's runup to the July 2019 critical design review in front of NASA. The thinking was that IXPE would need to fit inside the XL's 2-meter-long, 1-meter-wide fairing, meaning it would be phone-booth-sized when stowed. That was a problem, because the three telescopes had to be held in front of the detectors by a precise distance of 4 meters, the focal length created by the wide, glancing angles of concentric, cylindrical mirrors inside each telescope.

But a spacecraft of that length wouldn't fit in the XL. So the engineers chose Northrop Grumman's Coilable Boom technology, which has a history going back decades.

Once IXPE is in orbit, the LASP controllers will command three bolts to release the boom.

Stowed coiled up in a canister, compressed to a length of 290 millimeters — about one-thirteenth of the boom's final length — the boom's three rod-shaped fiberglass longerons, forming its backbones, will gradually release their springlike tension to unwind to the full 4 meters over the course of about three-and-a-half minutes. Then over the next minute and a half, the boom will gently oscillate as it settles into position, its flexibility protecting it from snapping or jolting the telescopes too hard.

Shortly after NASA approved this design came a surprise from the agency: IXPE would now be launched on a Falcon 9 rocket with its larger payload fairing. Shifting to a fixed boom, rather than an extendable one, might be possible, but would it be wise?

This twist prompted what Ball Aerospace's program manager for IXPE, MacKenzie Ferrie, calls an exercise in "engineering economics."

Switching to a fixed boom was tempting. As Weisskopf put it: "Anyone associated with NASA will tell you that anything to do with moving parts and space is always something to worry about."

In the end, the team decided that the cost and schedule limits would not have allowed a redesign.

The engineers also needed to ensure that IXPE's telescopes could direct the X-rays to each telescope's detector with the required precision.

They devised a threefold plan for precision: Determine how much margin the 15-millimeter-by-15-millimeter detectors had for alignment; test the deployment of the boom on the ground to see if the alignment with the detectors fell within that margin; and, just in case, install a motorized tip-tilt-rotate mechanism joining the boom and the telescopes' main support structure, or payload deck, so the alignment could be adjusted in space, if necessary. After deploying the boom in Ball's Boulder factory, Ferrie thinks it can be deployed within the margin and might never need a mechanical adjustment.

Previously, the engineers had thought about tracking the alignment with lasers but calculated that more equipment would add costs and that making multiple adjustments would induce wear and tear.

"You don't want to be torquing on the mirror modules that are 70 kilograms each while you're on a boom that is flexible," Ferrie explains.

New detector technology

In the 1960s and early '70s, Weisskopf and fellow scientists at Columbia University learned valuable lessons about the challenges to come.

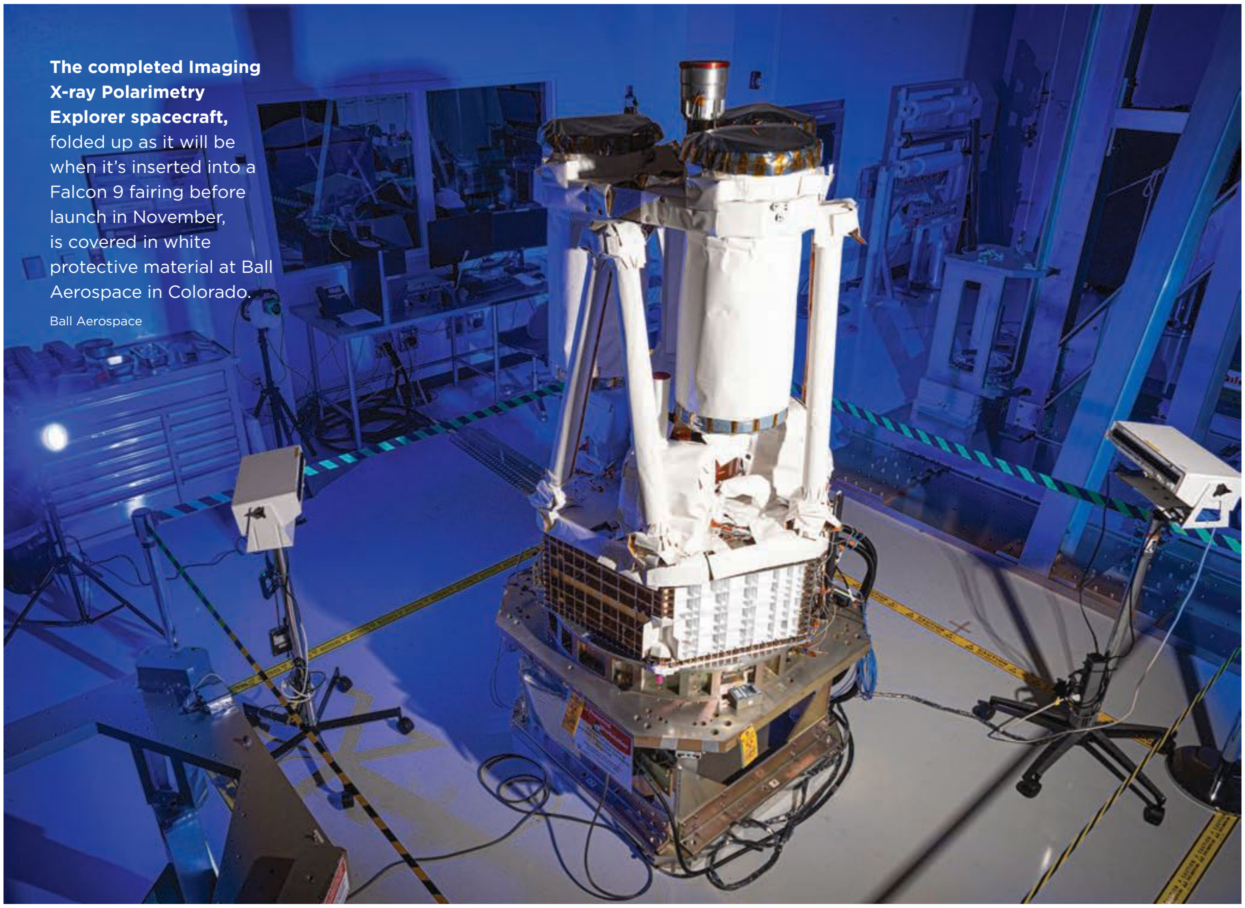
In 1968, shortly before Weisskopf arrived, Columbia scientists sent their first attempt at a detector to the fringes of space on a sounding rocket. If all went as planned over the span of five minutes, the polarimeter would reflect incoming X-ray photons off lithium blocks into surrounding small chambers known as gas proportional counters. When a gas molecule in a counter absorbed a photon, the molecule would eject an electron. By counting the electrons, and by extension the photons, the scientists would determine which counter received the most photons and from that calculate the direction of polarization.

Disappointingly, the instrument delivered no detections, so the scientists made a major adjustment for the second flight two years later. They added four additional polarimeters, each with graphite crystals that served the same function as the lithium blocks in the fifth polarimeter. The strategy worked: The team gathered X-ray polarimetry about a then-newly discovered pulsar 7,000 light years away, rotating 30 times a second at the center of the Crab Nebula, a supernova remnant and a bright source of X-rays.

Nevertheless, Weisskopf recognized the limitations of the photon-counting method. He came to realize that to make a bigger impact on astronomy, an X-ray polarimeter in space would need to create focused images.

Enter scientists from Italy's National Institute for Astrophysics and National Institute for Nuclear Physics and France's Institute of Nuclear Physics. After working with members of the Italian team on other projects, Weisskopf learned in 2000 that they had invented just such an X-ray detector relying on the photoelectric effect. In the concept, X-rays crossed a beryllium window and interacted with a layer of dimethyl ether gas whose molecules, when they absorbed an X-ray photon, ejected an electron like the old gas counters did. The electron traveled in the direction of polarization, ionizing more gas molecules along the way. These are the tracks that IXPE will image.

Weisskopf teamed up with the Italian scientists, and together with Ball Aerospace they developed the pitch that NASA ac-



The completed Imaging X-ray Polarimetry Explorer spacecraft, folded up as it will be when it's inserted into a Falcon 9 fairing before launch in November, is covered in white protective material at Ball Aerospace in Colorado.
Ball Aerospace

cepted in 2017. With Italy providing the dimethyl ether gas detectors, Marshall took responsibility for building IXPE's three cylindrical telescopes, and Ball Aerospace agreed to design and build the spacecraft body and to put all the elements together and perform testing.

Final jolt

Last year, IXPE officials received a second surprise, and this one was less pleasant than finding out a larger launch vehicle was available. The rounded, triangular aluminum deck that must hold IXPE's telescopes steady arrived warped from a vendor that Ball Aerospace said it won't name as a courtesy to the vendor.

Ball normally would have machined that part in house out of a solid block of aluminum, but the part was just a little too big for Ball's facility.

To evenly line up the telescopes with the detectors, the top of the structure needed to be even so the telescopes would be the same distance from their respective detectors.

"The whole structure was, like, warped," Ferrie says. "It looked like if you fried a potato chip." That wasn't going to work: "You want each mirror module" — aka telescope — "to be sitting on the surface at the same height."

The order had already taken eight weeks, with only a couple of weeks left in the schedule margin until the lack of the part would delay everything.

"'It's going to affect launch,'" Ferrie remembers thinking. "It was a huge deal."

A group from Ball flew out to the vendor.

"We had a lot of discussions over, 'OK, what was your machine speed — what would help?'" Machining away aluminum from a solid block at a fast speed, to create a thin wall, can contribute to potato chipping, Ferrie says.

Together the teams redesigned the structure to have ribbing on the back to provide support. They slowed down the machine speed and heat-treated the metal, subjecting it to hot and cold temperatures, earlier in the machining process to make it stiffer sooner, and they did that twice instead of once. They machined pockets out of the metal to make up for the added thickness of the ribs.

"Our machinists here and their machinists," says Ferrie, referring to the vendor, "along with our designers, came up with an amazing product that is actually lighter in the end."

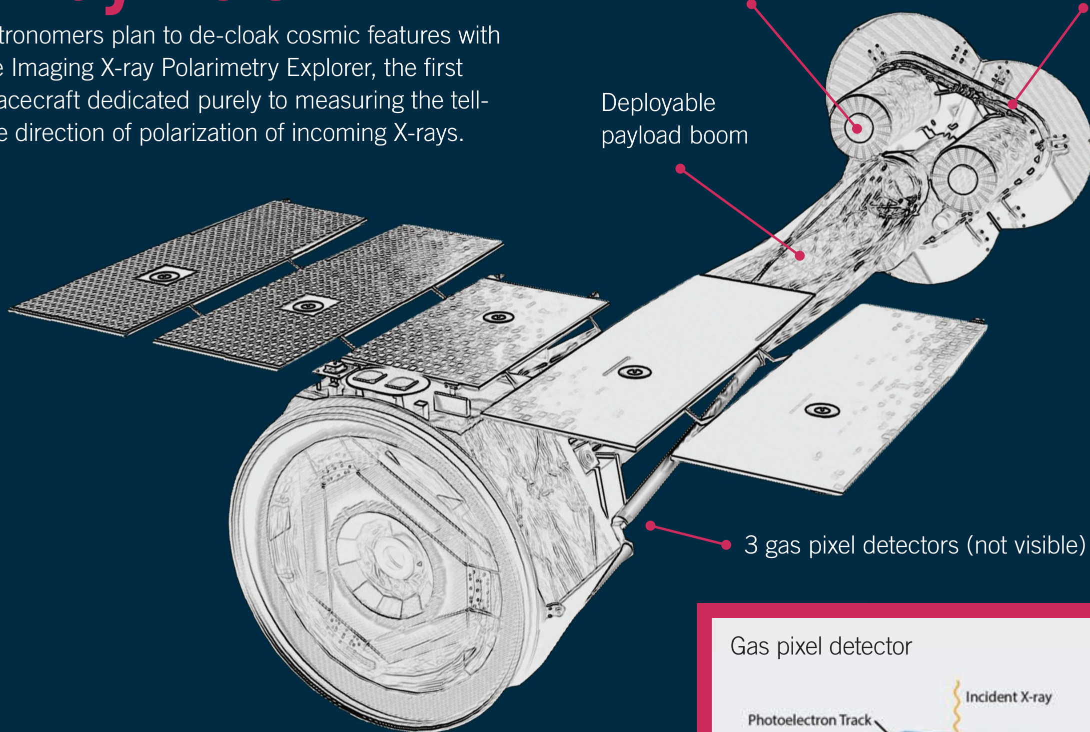
Her priority now until the launch: "Finishing the test campaign," Ferrie says. IXPE is about science and tax dollars and international collaboration. But it's also about achieving the vision of one very persistent scientist.

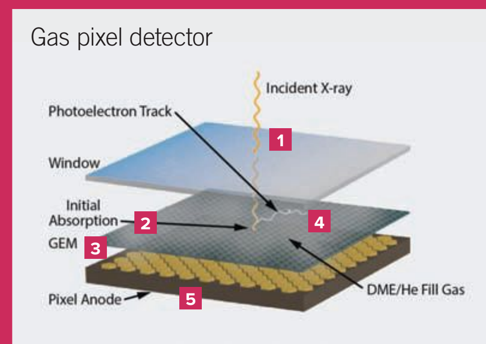
"We kind of always joke Martin has been waiting 70 years for this," Ferrie says, exaggerating the 50-plus years since Weisskopf took part in the sounding rocket launches.

The waiting may end as soon as November, the earliest IXPE could be launched. ★

X-ray vision

Astronomers plan to de-cloak cosmic features with the Imaging X-ray Polarimetry Explorer, the first spacecraft dedicated purely to measuring the tell-tale direction of polarization of incoming X-rays.





5 steps to measure X-ray polarization

Three identical 15-by-15-mm polarization-sensitive gas pixel detectors provided by the Italian Space Agency will create images that show the polarization direction of X-rays reflected from IXPE's three identical telescopes. Here's how the process works:

1 X-rays cross a 50-micron-thick beryllium window retaining a 10-mm-deep layer of dimethyl ether gas.

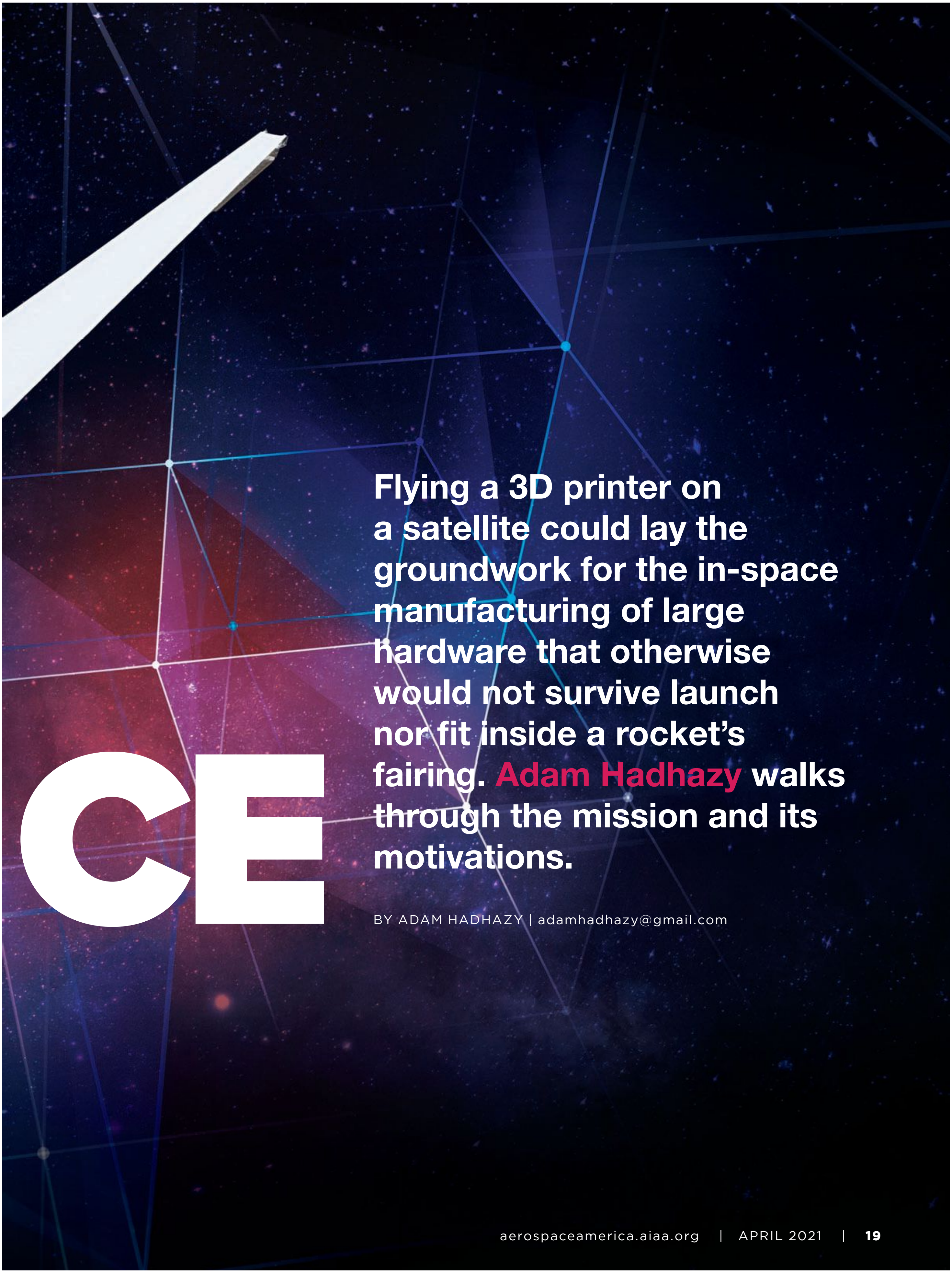
2 Gas molecules absorb X-ray photons and expel electrons in the direction of the plane of polarization. Expelled electrons ionize tracks through the gas, leaving more ionized electrons in their wake.

3 Gas electron multiplier, an electrified copper lattice at the base of the gas layer, collects the ionized electrons into electric fields — the holes in the lattice — where they ionize more of the gas molecules, amplifying their section of the electron track in a chain reaction.

4 When enough electrons get close to the detector's aluminum-topped pixel anode chip, the electrons generate a small electrical current that ends at the aluminum top.

5 Electronics register the electrical current, signaling that the pixel should be included in the image. A single millimeter-long track activates multiple pixels. The distribution of many tracks from the same X-ray source provides enough data for scientists to figure out the polarization statistically.

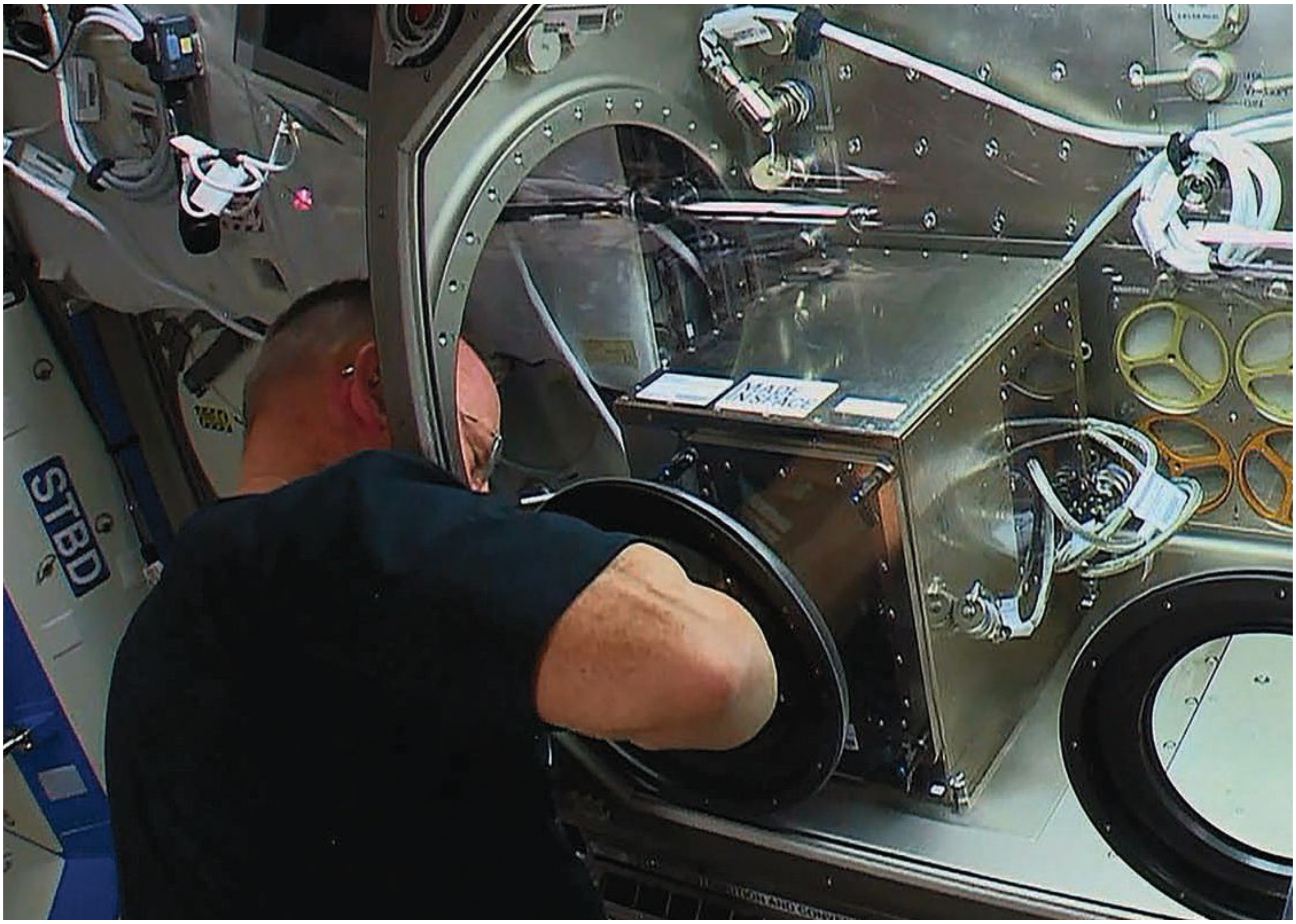
BUILDING FOR SPACE, IN SPA



CE

Flying a 3D printer on a satellite could lay the groundwork for the in-space manufacturing of large hardware that otherwise would not survive launch nor fit inside a rocket's fairing. Adam Hadhazy walks through the mission and its motivations.

BY ADAM HADHAZY | adamhadhazy@gmail.com



The paradigm that's held for nearly everything we've ever put into space, going back six-plus decades, is "make it here, launch it there." Although plenty successful, this paradigm has also proven to be stunningly inefficient. A satellite must be overdesigned and overmanufactured to withstand the heavy G-forces, violent shaking and sonic assault of launch and ascent, despite the fact that the satellite will spend its entire operational life in smoothly soundless weightlessness. Then there is the tyranny of the fairing. Because engineers can only make rocket nose cones so big, payload sizes are severely constrained.

NASA mission planners hope to flip this Space-Age-old paradigm on its head with the OSAM-2 mission, short for On-orbit Servicing, Assembly, and Manufacturing and formerly known as Archinaut. Plans call for a small spacecraft equipped with a 3D printer to additively manufacture a plastic beam, or boom, that will unfurl a simulated solar sheet into place. A robotic arm will swivel the printer around 180 degrees to print a second test boom.

If satellites can be programmed to sprout components in this manner, then an even bolder vision could lie ahead. Perhaps spacecraft parts could be manufactured in the vacuum of space from celestial raw materials and be assembled by robots into communications satellites, space station modules, or astronomical observatories. The result would be a vibrant economy in the final frontier, and one largely untethered from an Earth-to-orbit supply chain.

The $94 million OSAM-2 mission would be just the start, however. Still to be proven would be the ability to unfurl an actual solar sheet in space, perhaps even additively manufacture it and assemble multiple such sheets into vast, electricity-generating arrays. Today's arrays consist of solid panels that must be folded up inside fairings and subjected to the brutalities of launch, which limits their size and design. Solar arrays are just one example

▲ **NASA astronaut Barry "Butch" Wilmore** installs a Made In Space 3D printer on the International Space Station in 2014. While this device produced small items such as wrenches, researchers hope to prove that large structures can be additively manufactured in the airlessness of space.
NASA

"If you can do those three key elements — on-orbit servicing, assembly and manufacturing — you could open a design space for some really awesome things."

— Larry Huebner, NASA

of the changes to come. Engineers envision giant radar support elements and other structures. "What you want to manufacture is really limitless," says Tom Campbell, president of Made In Space, the lead developer for the OSAM-2 mission and a subsidiary of Florida-based space conglomerate Redwire.

Beyond OSAM-2, other researchers are devising robotic methods of refueling spacecraft and replacing worn or faulty parts. Among them are the members of NASA's OSAM-1 team, an in-house effort at NASA's Goddard Space Flight Center in Maryland in collaboration with Colorado-based Maxar Technologies. They plan to launch a "servicer" satellite in 2025 that will grasp, refuel and adjust the orbit of a guinea pig, so to speak, in the form of the 22-year-old Landsat 7 Earth imaging satellite operated by the U.S. Geological Survey.

"If you can do those three key elements — on-orbit servicing, assembly and manufacturing — you could open a design space for some really awesome things," says Larry Huebner, the NASA technical lead for OSAM-2.

While NASA has no expectations that OSAM-style capabilities will be ready in time to affect the agency's long-shot plan to return to the moon in 2024, it could factor into future launches under the Artemis program. "Artemis is about more than getting back to the moon; it's about sustained human presence on the moon and the ultimate goal of going to Mars," says Huebner.

Transcending the barriers of fitting in fairings and surviving launch loads by erecting factories in space could be the path forward to a sustained human presence.

"When you combine the capabilities of autonomous, in-space additive manufacturing with robotic assembly techniques, we see the possibilities for beginning to build a true infrastructure supporting human exploration, science missions, and eventually the economic development of space," says Mary Lynne Dittmar, president and CEO of Dittmar Associates Inc., and who formerly managed flight operations for Boeing's International Space Station program.

3D printing on high

When NASA awarded Made In Space the initial proof-of-concept contract in 2016, the company and NASA had already accumulated three years of lessons about 3D printing in space, albeit in the solar-protected, pressurized volume of the International Space Station's U.S. Destiny Lab with a flight engineer tending to it.

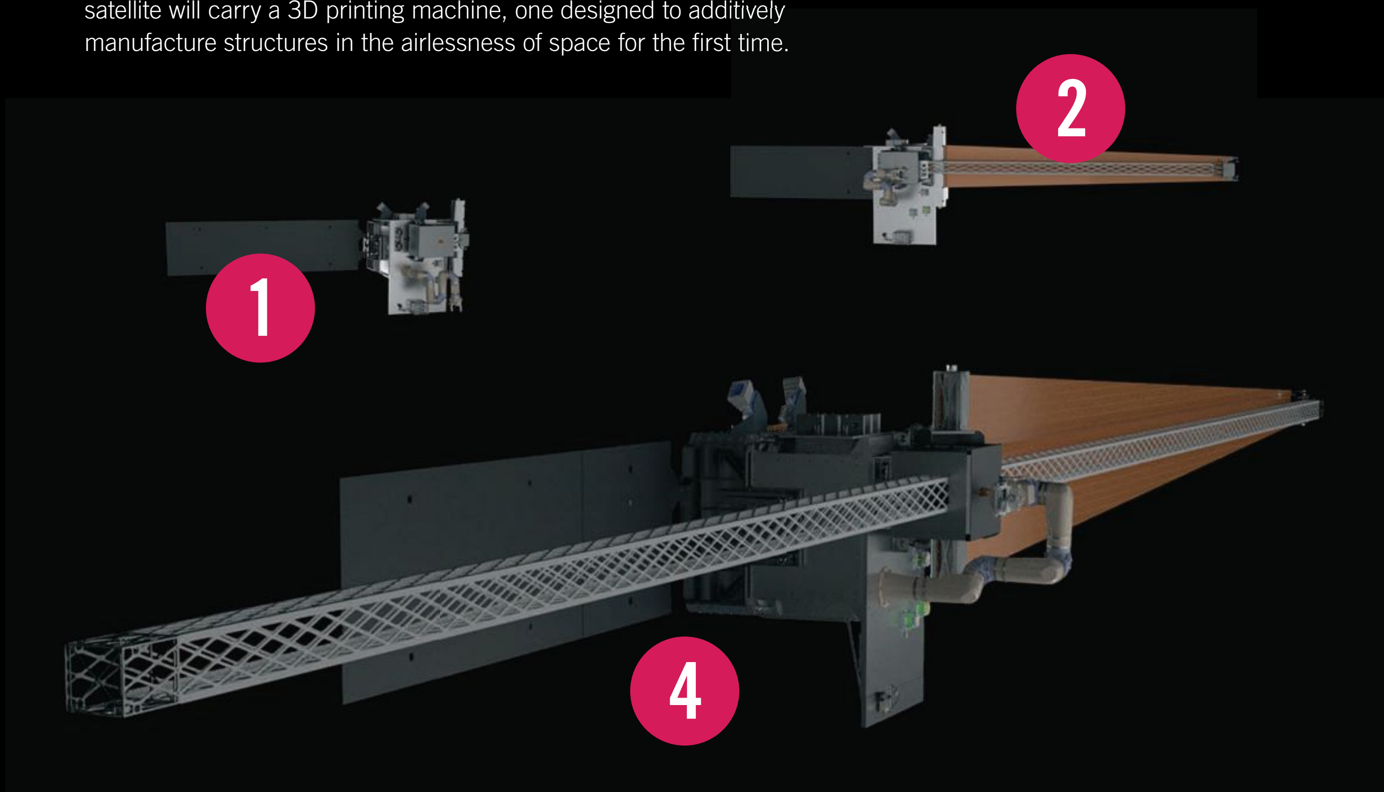
That engineer, former NASA astronaut Barry "Butch" Wilmore, recalls unloading the 3D printer from a Dragon capsule and setting up the apparatus. In the first print jobs, the extruded material would not adhere to surfaces. "We had some strange-looking objects that came out of the printer," says Wilmore, laughing. Via live camera feeds, Wilmore worked as "the eyes and ears," he says, for the Made In Space engineers on the ground as they sorted out the issue. Changing the angle of the pan where the melted plastic deposited and moving the pan closer to the nozzle troubleshot the problem, recalls Wilmore.

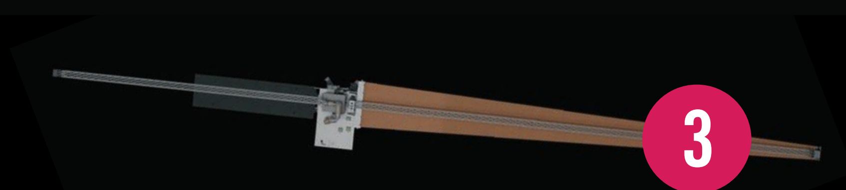
A design adjustment was also needed before the printer ever left the ground. Made In Space chose a well-established process on Earth, the fused filament fabrication technique, also known as fused deposition modeling. A spool feeds threads of plastic through a heated nozzle that melts the plastic and deposits the material one thin layer at a time, over and over, on a flat surface or starting block. The process continues until the printer achieves the designed size and shape of the intended object. Engineers needed to transfer heat away from the print head and away from the extruded, printed plastic so it would properly harden. In Earthly conditions, two modes of heat transfer — conduction and convection — readily accomplish these tasks. Conduction primarily involves heat transferring through solids, such as the pan that the plastic prints onto, but also through the air as gas molecules come into contact with heated surfaces and absorb heat. At that point, the second mode of heat transfer, convection, whisks away warmed molecules and brings in fresh ones that soak up heat and carry it away. Convection requires fluid flow, something that occurs naturally on Earth whether the fluid is a liquid or gas. Such flow does not happen naturally on the station, because the station and everything inside it, including the air, are in free fall due to gravity, giving the illusion of weightlessness. A parcel of denser cool air there-

▲ **Made In Space engineers** prepare the Extended Structure Additive Manufacturing Machine, or ESAMM, for thermal vacuum testing at NASA's Ames Research Center in California.
NASA

3D printing in space

OSAM-2, the On-orbit Servicing, Assembly, and Manufacturing-2 spacecraft, will be launched as a rideshare payload on a Falcon 9. The satellite will carry a 3D printing machine, one designed to additively manufacture structures in the airlessness of space for the first time.





1. Satellite arrives on orbit.
2. Extended Structure Additive Manufacturing Machine 3D-prints a 10-meter beam, which unfurls a simulated solar collector.
3. xLink robotic arm locks beam into place and rotates ESAMM 180 degrees so that it can manufacture a 6-meter beam.
4. The full satellite with extended beams.

What you need to know

WHO BUILDS WHAT

Printer — Made In Space, Florida

Satellite bus — Blue Canyon Technologies, Colorado

Robotic arm — Motiv Space Systems, California

Falcon 9 launch vehicle — SpaceX, California

FUNDING

NASA — $94 million ($73.7 million to Made In Space; includes launch costs)

Made In Space — 25% of total mission costs

SOURCES: Art, Made In Space; text, Aerospace America staff research from NASA and Made In Space sources

NASA has another On-orbit Servicing, Assembly, and Manufacturing spacecraft in development. It's called OSAM-1, but it will launch after OSAM-2. The spacecraft, bottom, will test satellite-servicing technologies by grasping and refueling the aging Landsat 7 satellite.
NASA

“When you combine the capabilities of autonomous, in-space additive manufacturing with robotic assembly techniques, we see the possibilities for beginning to build a true infrastructure supporting human exploration, science missions, and eventually the economic development of space.”

— Mary Lynne Dittmar, formerly of Boeing

fore does not sink naturally into the less dense warm air, as it does on Earth, triggering circulation. Left to its own devices, the station’s internal atmosphere is accordingly stagnant, says Paul Shestople, Made In Space’s project manager for OSAM-2.

Knowing this, the Made In Space engineers instead induced artificial convection with a fan that blew air around the station’s 3D printer. “Without gravity or a fan, the hot molecules just sit there [on a hot surface],” says Shestople. “You can force convection with a fan. That’s what we do on the ISS, which has atmosphere but microgravity.”

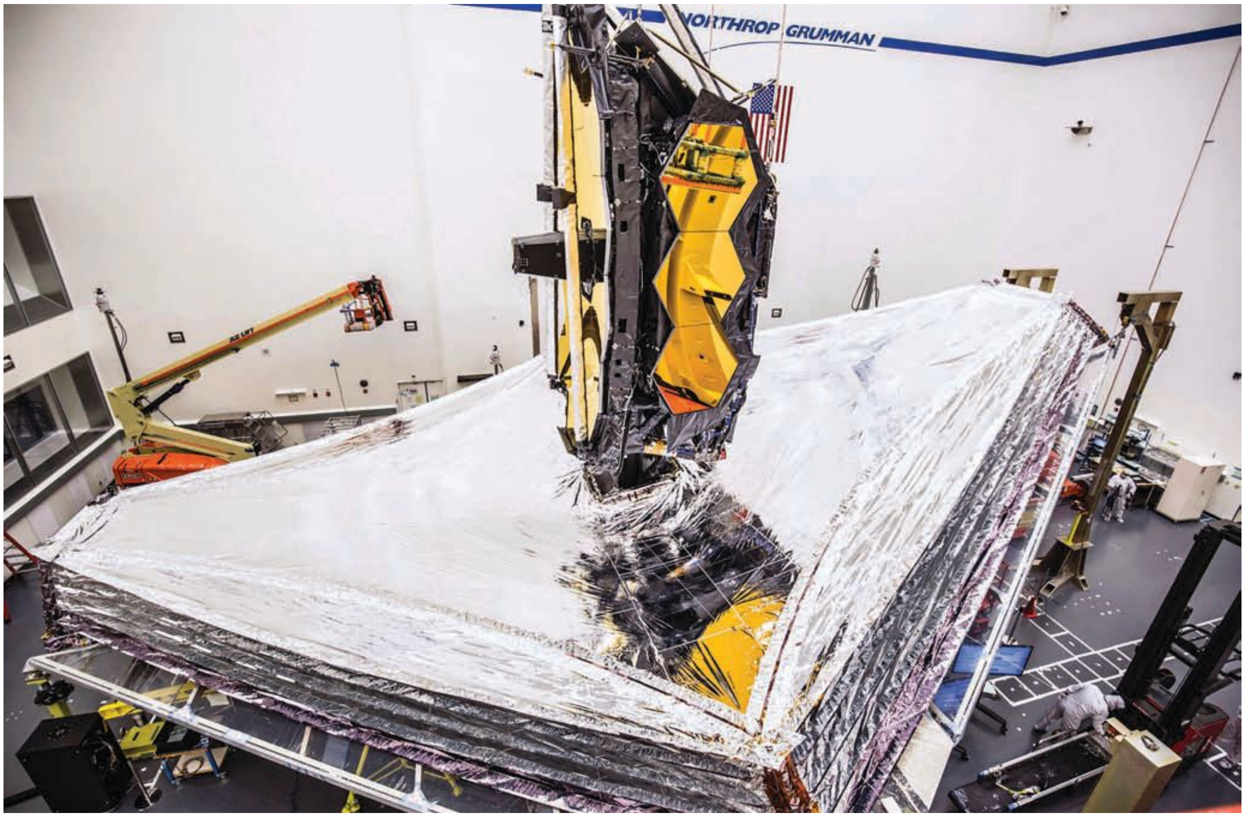
That solution, however, won’t do in the airlessness of space.

Truly “made in space”

Shestople and the Made In Space engineers therefore devised a new, space-tailored 3D printer for OSAM-2 dubbed ESAMM, for Extended Structure Additive Manufacturing Machine, the device that the robotic arm will swivel. “ESAMM is made for building in zero-G and very low pressure, very low atmosphere, and through a wide variety of temperature swings,” says Shestople.

Those temperature swings further complicate the dynamics of desirable heat transfer. Although interstellar space sits only a smidge above absolute zero at minus 270 degrees Celsius (minus 455 degrees Fahrenheit), thankfully, the Earth is close enough to a star and radiates enough heat that the mercury doesn’t plummet that low. Instead, engineers must deal with the wild differences between “night,” when an orbiting spacecraft passes through Earth’s shadow, and “day,” when the spacecraft is hit with direct sunlight. In shadow, temperatures can plunge to ballpark minus 100 degrees Celsius (minus 148 degrees Fahrenheit), while in direct sunlight, temperatures spike to around 100 degrees Celsius (212 degrees Fahrenheit).

In such an airless and extreme thermal environment, versus an air-filled room or space station module, engineers have to exert exceptional control over the various paths of heat transfer to print accurately. “The main difference, as far as how you do that, is paying attention to those heat paths,” says Shestople. “You need to make sure that the area where the printer is printing is maintained at a good temperature profile, while at the same time making



▲ **The James Webb Space Telescope's sunshield** is so big that engineers had to figure out a way to fold it into an Ariane 5 rocket fairing and then deploy it in space, technology that added significantly to the cost of the overall project. The OSAM-2 demonstration of 3D printing in space could be critical to avoiding such problems in the future.

NASA

sure you can take heat and transfer it away from that area so it doesn't get red hot."

Radiation, a third mode of heat transfer conveyed by electromagnetic waves (that is, light, typically infrared), does some, but far from all of the necessary heat transfer for OSAM-2's print head. "The print head is inside the satellite and is pretty small," says Shestople. "It doesn't have sufficient radiative surface to get rid of all the heat it generates." The engineers therefore had to find a way to pull more heat from the print head to cooler areas within OSAM-2, and they did, courtesy of the metal copper, an excellent heat conductor. "Since we can't rely on convection, the heat has to be conducted away through the printer surface and printer elements," says Shestople. "Unfortunately, there isn't enough conductive material to transport enough heat away, so we augment it with copper straps." The overall design shuttles this heat to external surfaces of the spacecraft to radiate away into space — the eventual fate of all the heat generated on OSAM-2, seeing as there is nowhere else for it to go.

For proprietary reasons, Made In Space won't go into further details. Nor will the company reveal the polymer OSAM-2 will use, except to say it must resist degradation by ultraviolet light, which is a challenge outside the shelter of an ISS module. Made In Space has, however, tried the aerospace-grade polymer, PEI/PC, or polyetherimide/polycarbonate aboard the space station and in ground tests of ESAMM, suggesting this may be the polymer of choice.

Those tests, performed in 2017, were part of the $20 million proof phase to demonstrate that ESAMM could churn out beams in simulated space conditions. Based on that success, NASA's Space Technology Mission Directorate then awarded Made In Space a $73.7 million contract in 2019 to carry out the mission, provided the company covered additional expenditures amounting to at least 25% of the total mission cost. The contract brought the latest version of ESAMM through testing in late 2020 at a Jacksonville hangar, confirming the printer can operate in weightlessness. Testing ESAMM on a free-falling airplane (in popular parlance, a vomit comet) was never feasible, given the too-short-for-printing, half-minute windows of micro-G such planes provide. Instead, through a gravitational sleight of hand, engineers effectively mimicked printing in weightlessness. The engineers pointed the printer up in order to print a beam vertically, attached a wire to the top of the forming beam, and then ran the wire through a pully to a counterweight. As the beam increased in length and mass, the team added mass to the counterweight, thus effectively counteracting the mass of the beam.

The development of the rest of OSAM-2 has likewise proceeded in recent months. In December small-satellite maker Blue Canyon Technologies of Colorado provided the spacecraft's bus to another OSAM-2 subcontractor, Northrop Grumman, which will further assemble and install OSAM-2's elements. One of those will be the robotic arm, provided by Motiv Space Systems of California. The engineering design unit — a rough-draft version of the arm, made of less expensive materials and not fully vetted for flight — was readied earlier this year.

Cosmic print shop

After its several years of development, OSAM-2 is now up for a critical design review midyear and is slated for launch no sooner than 2023. Should OSAM-2 proceed into full fabrication and fly, the satellite would enter a low-Earth orbit and ESAMM would begin its first print job, a beam 10 meters long extending out into space. A unique situation with 3D printing in the vastness and weightlessness of space, Made In Space's Campbell points out, is that there is no limited or defined printer volume, as is the norm for 2D and 3D printers. Instead, so long as ESAMM has raw material fed into it, it can print beams to extreme lengths in marked defiance of rocket fairing-imposed limits.

As this beam grows, it will pull the film-like simulated sheet made of Mylar, Kapton and other materials from a compartment at the base of the beam until it stretches the length of the beam. The film will be about the same thickness and flexibility as an actual sheet of flexible solar material. Initially, Made In Space was going to unfurl an actual solar sheet, but this plan was scaled back to a simluated one.

The benefits of a broad shift to flexible solar materials would be considerable, given the significantly greater surface area that flexible arrays could provide compared to the standard, fairing-folded arrays. In the specific case of the relatively small, refrigerator-sized OSAM-2 spacecraft, the proposed solar sheet would have generated five times as much power as a traditionally sized array.

After the first beam prints, the robotic arm will flip ESAMM around in order to print a beam out of the other side of the spacecraft. The fabricating of this second beam, measuring 6 meters, would demonstrate the ability to handle multiple jobs, while hinting at the sort of on-orbit object manufacturing complexity that could be achieved once coupled with robotic arm-enabled assembly.

As a bonus, printing these kinds of long beams in weightless space requires less material than if the same beams were made under gravity's relentless pull, says Shestople. That weight forces one to include thicker, load-supporting elements. Proving out just how much less material one could skate by with would be the province of a future mission. For now, as the first mission of its kind, engineers intend to load OSAM-2 with about 50 kilograms of printer stock material, enough to print beams matching those already produced and tested at Earth-level gravity. "There's the saying 'test like you fly, fly like you test,'" says Shestople.

An enhanced future in space

Although at this point, the additive manufacturing process would be a slow one — with the entire OSAM-2 demonstration expected to take several weeks, including some stoppage time built in for assessment — the overall time and cost savings of this approach to building space hardware should be significant, Shestople says.

He points to the James Webb Space Telescope, the NASA flagship astrophysics mission, as a prime example. Wildly overbudget and behind schedule, its original 2007 launch and $500 million price tag have since slipped to late 2021 and swelled to $9.6 billion including cost of operations. A major reason: In order to stay extremely cold for conducting infrared observations, Webb requires a tennis court-sized sunshield. That piece of hardware is far too big to fit in any of today's fairings. Engineers have thus had to devise means of folding up the sunshield like an umbrella to squeeze within an Ariane 5 rocket's standard 5-meter-diameter fairing. The shield has to then unfold and stretch taut in space, a process that involves 139 actuators, eight motors and thousands of other components. Nightmarishly, engineers have had to test and retest this mechanism in terrestrial gravitic conditions, completely unlike the actual scenario in space, as well as ensure that all components can endure the strain of launch and ascent.

"With [OSAM-2] technology, you're not designing these super-complicated mechanisms like on JWST, you're building structure on-orbit and assembling it there," says Charlie Adams, the NASA mission manager for OSAM-2. "That's an advantage."

This liberation from Earth's gravity well could jump-start space exploration and eventually empower a genuinely space-based economy, OSAM-2's backers say.

"To carry out human missions, we need to put a basic infrastructure in place — power, water, communications — oxygen, since we're in space — transportation, et cetera," says Dittmar. She calls OSAM-2 a "significant step" toward proving that those power needs, which are the linchpin for everything else, can be met.

"If we want men and women to live and work in space, there's got to be an economy there," adds Campbell. "And to have an economy, you've got to have manufacturing." ★

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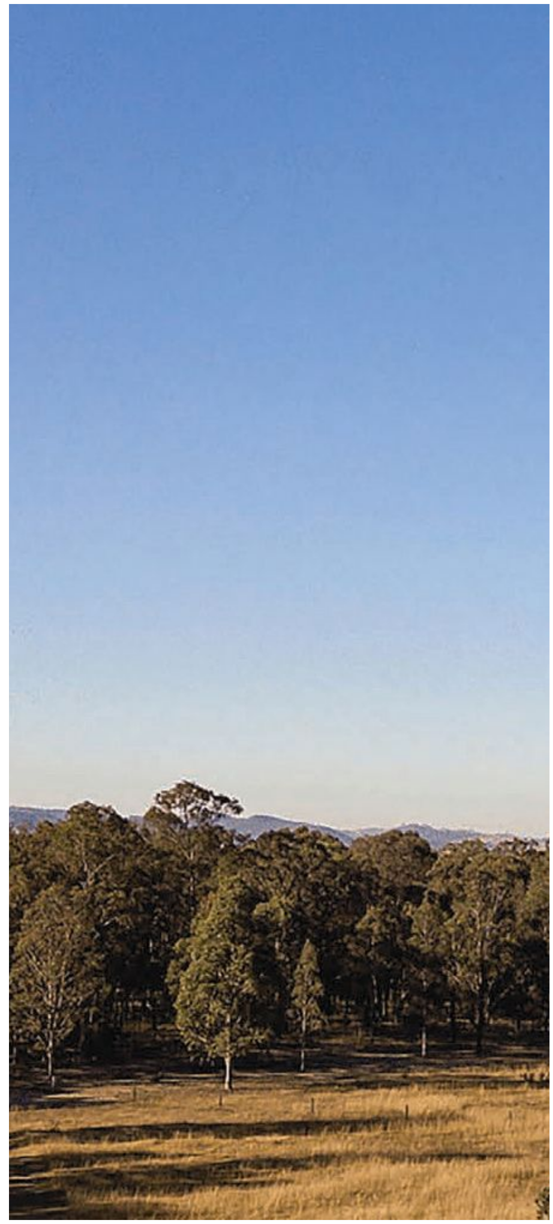
AIAA
SHAPING THE FUTURE OF AEROSPACE

VENTURING THROUGH THE PANDEMIC

Here at Aerospace America, we're not entrepreneurs, but we talk to a lot of them. We can imagine the daunting prospect of vying for venture capital during what we all hope is now a waning global pandemic. Our contributor Amanda Miller went scouting for facts and insights that aspiring entrepreneurs ought to know. Here is what she discovered.

BY AMANDA MILLER | agmiller@outlook.com



As the covid-19 pandemic hit the United States, experts throughout the venture capital world predicted that investments in startups would drop off, that the VCs — venture capital firms — would opt to reserve cash rather than invest it in case they had to shore up the finances of startups they already had a stake in.

That proved true.

As the pandemic took hold in March 2020, venture investing dropped off steeply, according to a midyear special report by Silicon Valley Bank, known for its tallies of venture investments. The bank called the period a "strange economic moment" of tumultuous fluctuations in venture investment from one month to the next. In its January 2021 report, the bank noted that investors had continued to raise funds but were cumulatively holding back a record $152 billion in reserves. The implication was that an upturn in investing could be at hand as the pandemic eases.

Even with buildup of reserves, investments picked up in terms of numbers of deals and dollar amounts, with 2020 likely topping 2019 in terms of total money, according to Venture Monitor, a quarterly report from the National Venture Capital Association and PitchBook Data, a firm that gathers business information about investors, startups and their deals. However, the growth was still modest compared to what the sector is accustomed to.

One executive said he expects the aerospace sector to suffer less from these fluctuations than other sectors. "The longer time horizon and bigger investment totals" in aerospace tend to buffer new companies from short-term ups and downs, says Chris Moran, general manager of Lockheed Martin Ventures in Palo Alto, California.

"Broad economic problems always cause the startup ecosystem" — both startups and investors — "to pause, belt tighten and then return with a new focus on what will be important post the slowdown," he predicted.

Moran was one of those who planned to reserve cash in case any startups in his company's investment portfolio needed it.

Decisions to reserve cash are felt less severely by startups that are already safely in investment portfolios. In 2020, these late-stage startups claimed a larger share of investments, including a record number of "mega-deals," while the pandemic proved to be "a more challenging fundraising environment for newer entrepreneurs," including "female founders" who "have traditionally been underrepresented in VC funding," Venture Monitor said in its January 2021 report.

Of course, investment dollars aside, those still early in the product development phase did not yet have customers to lose due to the pandemic: "They weren't dependent on that revenue," Moran says.

Choosing to become VCs

The trend of large aerospace corporations investing in startups began over a decade ago and took off during the past few years, when some of the major contractors realized how furiously startups were innovating.

"There was a sense that the world is rushing ahead," recalls Logan Jones, who until last June was

the Boeing vice president in charge of the company's HorizonX unit and its venture capital arm. He left to lead a new subsidiary of SparkCognition, an artificial intelligence company in the HorizonX portfolio.

The big three of Airbus, Boeing and Lockheed Martin each now operates a venture capital arm. These units scout for promising startups to add to their investment portfolios, and later these venture arms might help cultivate business leads or loop in technical experts.

Of the three, Lockheed Martin Ventures lays claim to the earliest investments, dating back to 2007, though 36 of the 56 companies Lockheed Martin Ventures has invested in have joined the portfolio just since 2016.

Airbus Ventures started investing in 2016 and lists 39 companies in its portfolio, including the space debris-mapping company LeoLabs, which operates radars in Alaska, New Zealand and Texas to track objects in low-Earth orbit.

Boeing established HorizonX Ventures the following year and has invested in 34 startups, including nine in 2020.

The companies usually don't disclose specific investment amounts for competitive reasons. HorizonX says typical investments in earlier-stage companies range from $1 million to $10 million.

The big three may make investments that are less about a near-term profit, as the executives tell it, and more about advancing technology that could further certain broader strategic goals, either for the corporation itself or for the startups in its portfolio.

Boeing's HorizonX, for example, invests in focus areas ranging from future mobility to autonomous systems, advanced manufacturing and space, similar to Airbus Ventures' portfolio categories that include autonomy, electrification and materials.

▲ **Airbus Ventures** invested in Dendra Systems, a company that builds and sells drones, like this one that spreads seeds to restore natural landscapes.

Dendra

▲ **LeoLabs' radar** network includes the Kiwi Space Radar in New Zealand. Airbus Ventures has invested in LeoLabs.
U.S. Embassy

Lockheed Martin Ventures lists 10 areas of interest including autonomous systems, robotics, cybersecurity and space.

Venture execs for the big three say they largely prioritize seed-stage companies — startups that may be no further along than a couple of people in a garage with an idea, or who may have reached the point where they're ready to start going after customers.

"We've always taken the mindset of 'the earlier, the better,'" says Brian Schettler, the new head of HorizonX who replaced Jones. "We want to help mature the technology."

At Airbus Ventures, Managing Partner Thomas d'Halluin reassures startup founders that an investment is "all about venture capital" — not, as some fear, a "down payment" on a future acquisition.

The big three also have added more than aerospace companies to their investment portfolios.

HorizonX invested in C360, an entertainment company specializing in panoramic video of sports events in 2017 because its software can replay massive amounts of video in near-real time.

And in 2015, Lockheed Martin Ventures provided Kampachi Farms, a fish hatchery operator since renamed Ocean Era, with satellite communications technology in exchange for an equity stake.

Who you are counts

The investors say that once they're interested in a startup, they place a lot of weight on the founders' expertise, leadership skills, business sense and reliability — even more so than the product they're pitching.

Then, of course, there is the quality of the business case that startups present — whether they've quantified their pitch with research into marketing channels, customers and market trends and how all those things fit together.

"When they haven't thought through the value proposition, it's harder to make an investment in those companies," says Jones, the former HorizonX chief who now gets to practice what he preaches in his new job as general manager for SparkCognition Government Systems. His role there includes attracting investors.

> “The longer time horizon and bigger investment totals” in aerospace tend to buffer new companies from short-term ups and downs.
>
> — Chris Moran, Lockheed Martin Ventures

▲ **Matternet is** a California startup that received funding from Boeing HorizonX Ventures. Matternet’s products include its M2 delivery drone, which it says can carry medical cargo up to 2 kilograms and 4 liters as far as 20 kilometers.

Matternet

> **“We’ve always taken the mindset of ‘the earlier, the better.’ We want to help mature the technology.”**
>
> **— Brian Schettler, Boeing HorizonX Ventures**

Airbus Ventures’ first investment was in Local Motors Inc., a startup whose autonomous shuttle is being tested at several locations.

Local Motors Inc.

Even when cash isn’t tight, Moran at Lockheed Martin Ventures notices whether founders keep an eye on their cash flow — how often they get behind and need to urgently ask for more:

“After a couple times, you sort of lose confidence in the CEO.”

Aerospace-savvy investors

Sam Stonberg is one of Lockheed Martin’s “venture leads,” someone assigned to scout for startups that can fill unmet technology needs, in his case for Lockheed Martin Space in Colorado. He says there’s a reason many startups would rather accept an investment from a company such as Lockheed Martin Ventures than, say, a tech venture capital firm that might not have aerospace expertise. In terms of non-venture funding, Stonberg has written letters of support for startups applying for Small Business Innovation Research grants from the U.S. government.

“Our money is different in a way,” Stonberg says. It comes with perks, including the expertise of Lockheed Martin’s engineers and managers and the potential to land Lockheed Martin as a customer right away.

Shey Sabripour founded phased-array satellite communications company CesiumAstro in Austin, Texas, in 2017 and raised the company’s first round of capital from Airbus Ventures. He says his counterparts there are “so hands-on” and that they encouraged him to network with other companies in the portfolio for business leads.

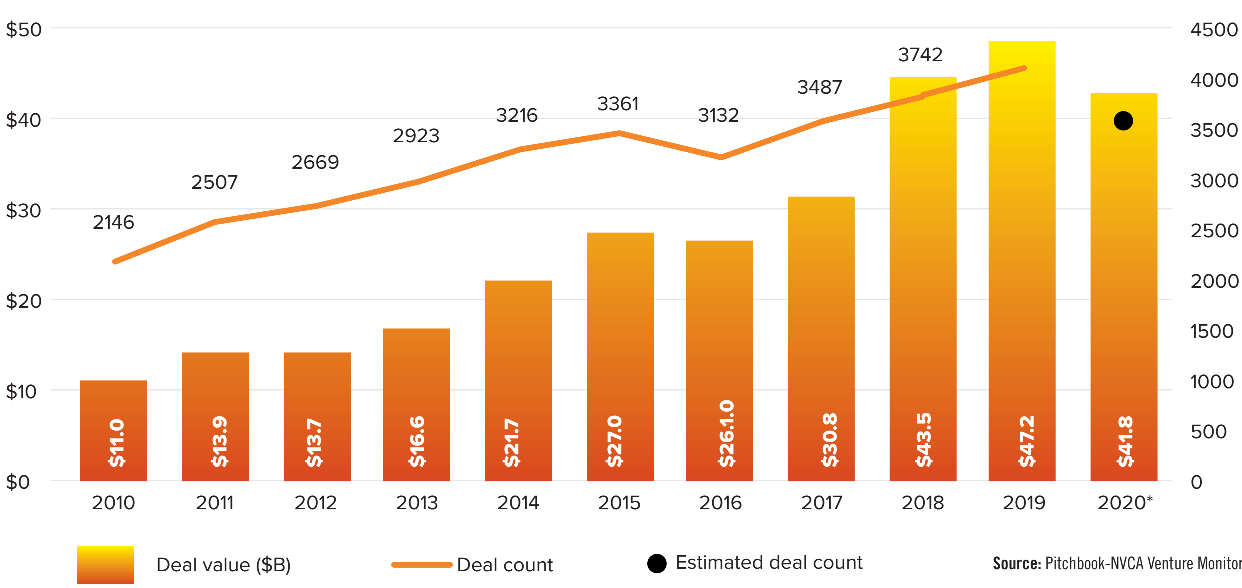
Most promising tech trends

When I asked investors to identify what they see as the most promising technology area, most couldn’t settle on one:

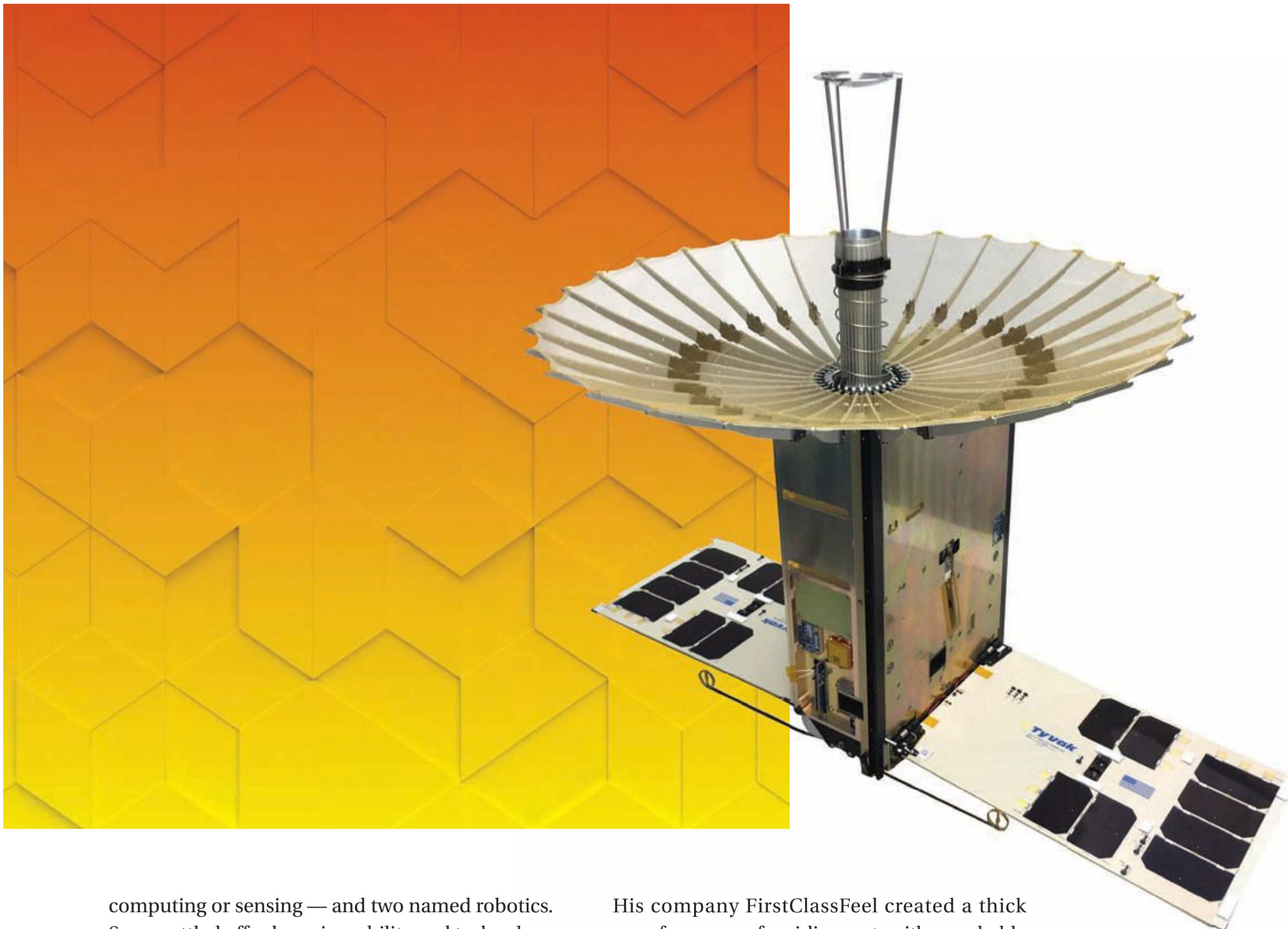
Four named autonomy. Two pointed to advances in quantum physics — atoms harnessed for

Weathering the pandemic

United States venture investments dipped, but by no means collapesed last year as the pandemic gripped the world.



Source: Pitchbook-NVCA Venture Monitor



▲ **RainCube, developed** and operated by Tyvak Nano-Satellite Systems with NASA's Jet Propulsion Laboratory, was a technology demonstration to collect data with a weather radar small enough to fit on a cubesat. Lockheed Martin Ventures invested in Terran Orbital, Tyvak's parent company.
NASA

computing or sensing — and two named robotics. Some rattled off urban air mobility and technology to power deep space missions. Two mentioned artificial intelligence, and two brought up space tourism.

"Who doesn't want to go to space and look down on Earth?" says Anthony Previte, president and CEO of Tyvak Nano-Satellite Systems in Irvine, California, and a board member of the technology investment firm Starsmith.

Staying the course

The temptation to stray from the established plan — to try to add a new product, for example — stalks startups even under the best of circumstances, says Previte.

Tyvak received an investment from Lockheed Martin, but with 160 employees in the U.S. and abroad, Tyvak is no seed-stage startup. A self-described serial entrepreneur, not to mention an expert in ultra-low-frequency radio astronomy, Previte has learned to stay true to the business plan at Tyvak:

"We don't bother with other things that end up driving costs and driving schedules."

His fellow Los Angeles-area entrepreneur Jack Somers, a master's student at the University of Southern California, learned that lesson last April in advice from a mentor in the school's Iovine and Young Academy, which offers a cross-disciplinary degree spanning design, business and technology.

His company FirstClassFeel created a thick memory foam cover for airline seats with a washable top layer of antimicrobial fabric. Before the pandemic, he already had a U.S. patent and a factory lined up in China to start making the seat covers.

Then, anticipating that people would want to start covering their office chairs, too, he started to work on that idea. But a mentor within the academic program advised him to "stay the course," instead suggesting that Somers pivot to pitch the seat, both to investors and directly to airlines, as a way to reassure pandemic-anxious travelers.

Timing and the low-cost way in

If the pandemic drags on and investors continue to hold out on the newest startups, you might wonder if it's even worth trying to start a company right now.

Moran at Lockheed Martin Ventures has a tip: If you don't have the money to build hardware, start on the software. Cloud computing platforms such as Amazon Web Services have brought the costs of software development way down.

But is it possible that the time's just not right? Maybe.

"It's a very complicated set of attributes that all have to be aligned to make successful startups work. You can't control timing. A great idea at the wrong time won't be a great idea," says HorizonX's Schettler.

"But our no's aren't forever no's," he says.

"The timing might be right down the road." ★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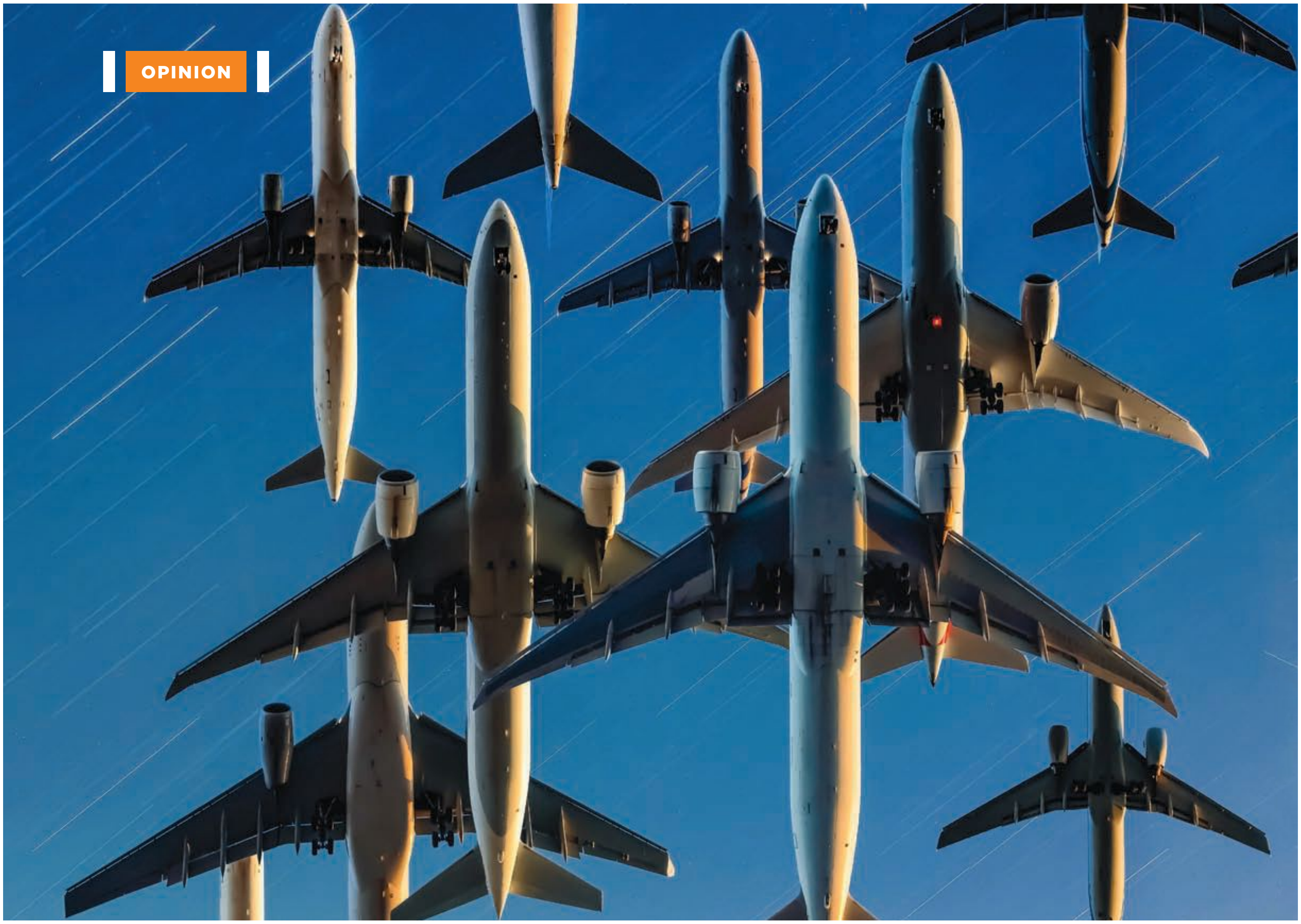


Decarbonizing by 2050: Optimists, pessimists and realists

The air transportation sector once believed that the best it could do globally speaking would be to reduce its net-carbon output by 50% below 2005 levels by 2050. That view placed the sector out of sync with what the United Nations has called a "global rallying cry" and "race" toward a net-zero economy by 2050. Now, a shift is underway that could sync up the sector with those embracing the more ambitious goal. Airline strategist Asteris Apostolidis weighs the sector's technology options for getting there.

BY ASTERIS APOSTOLIDIS

For every kilogram of kerosene an aircraft engine consumes, approximately 3 kilograms of carbon dioxide are emitted, according to the International Civil Aviation Organization's Carbon Emissions Calculator. A large jet engine consumes a kilogram every single second during cruise, so by multiplying this figure with the number of aircraft flying at any given moment, the total emissions escalate rapidly to hundreds of millions of tons per year. During the last decades, carbon that was stored underground for millions of years has been released in vast amounts into the atmosphere, and of that all forms of air, land and sea transport combined account for around one-fifth of global carbon dioxide emissions.

Increasingly, the need for aggressive emissions reductions is being recognized by airlines, airports and others. Europe's aviation sector unveiled in February its flagship sustainability initiative, Destination 2050. According to this plan, all flights within or departing from the European Free Trade Association, the European Union and the United Kingdom must be CO_2 net-zero by 2050, a dramatic step beyond the sector's global target of a 50% reduction by that year, a goal set by the International Air Transport Association in 2009 and at the time one of the first global commitments by a sector. The catch for the new, more aggressvie goal is that flights bound for Europe are excluded for now, but of course this is something that could change if similar commitments are made by the countries of departure. In the United States, the new administration has set the ambitious target of a net-zero economy by 2050, in line with the global climate action under the Paris Agreement. However, it is not clear whether this will be reflected in introduction of even stricter emission goals for air transport in the U.S., similar to the ones in Europe. The stakes are enormous, because it's far from clear that a 50% reduction in emissions would be enough to meet the climate goal of the Paris Agreement, which seeks as a worst case to hold the temperature rise to below 2 degrees Celsius, while pursuing efforts to limit the increase to 1.5 degrees.

For sure, decarbonizing the whole transportation industry will be an enormous undertaking, including for the air transportation sector. Let's look at the various paths and trade-offs for reaching net-zero in our sector by 2050.

Grappling with weight and range

In aviation, weight is critical. No matter how effective a decarbonization technology is expected to be, it cannot be implemented if it imparts a nonacceptable weight penalty on the aircraft. In other words, this is a firm design constraint. Batteries are an example of a technology that works great in road vehicles, because weight is of less concern. However, in the context of commercial aviation, battery-electric flying shouldn't be expected anytime soon, with the exception of small, regional aircraft. That's because the energy that batteries can store per kilogram (known as specific energy) is still far lower than the specific energy figure for kerosene. Also, the weight of batteries stays permanently with the aircraft, affecting negatively its performance throughout a trip and requiring reinforced undercarriages for landings. On the other hand, fuel is exhausted during the flight, making aircraft lighter with flight time and allowing for fuel dumping in case of emergencies and avoiding overweight landings.

Range is also an important performance metric, since current long-haul aircraft can fly nonstop almost everywhere in the world. This convenience comes with a significant fuel penalty, however, as airplanes must lug fuel that will be used only after many hours of the flight. Research has shown that short refueling stops in long-haul flights could improve fuel efficiency, something that could be required in the future by regulators in order to curb emissions. Range, in contrast to weight, can be considered a soft constraint, meaning that some passengers will not be happy if their flight includes stopping to refuel for the sake of reducing emissions, or if they have to switch to a charged electric aircraft for the final leg. This is also the case with electric cars, as their drivers have to take longer breaks to recharge them during long trips, while refueling in comparison only takes a few minutes.

Batteries can't power long-haul flying

Something important to also take into consideration is that the vast majority of emissions from commercial aviation can be attributed to long-haul flying. According to EUROCONTROL, the European organization for the safety of air navigation, approximately half of air transport CO_2 emissions come from long-haul flights, which represent only 6.2% of total departing flights in Europe. In other words, many of the technical solutions under development that aim to reduce the carbon dioxide emissions of flying focus on regional and short-haul flying, while the most important gains would come from long-haul. Of course, most technologies need to be implemented in smaller aircraft before being scaled up to bigger ones, but we need to keep in mind that wide-body aircraft must also be part of the solution, independently of how aggressive the different countries will finally be in their 2050 aviation emissions targets.

Focusing on the different options for long-haul flying, electrification of planes does not seem applicable in the Paris Agreement time frame. Again, here the main impediment is the increased weight and volume of batteries, unless some step changes in technology take place. However, electrification can realistically be expected at the second half of this century, according to the analysis, "Technological, economic and environmental prospects of all-electric aircraft," in the journal Nature Energy.

In addition, the business model of airlines will need to be adapted to the operational particularities of electrical components, since batteries will have to be recharged, a process that needs much more time than refueling with jet fuel. Also, the electricity production needs would skyrocket under a shift to an electrified global fleet, requiring significant investments in renewable energy for aircraft to be recharged.

Hydrogen shows promise

Batteries do not seem anywhere close to widespread application, which is why the industry has begun placing so much emphasis on hydrogen as an option. Hydrogen can either be held in fuel cells, producing electricity and acting as an alternative to batteries, or directly combusted in gas turbines, in a similar way with conventional fuels. Both options have various advantages and disadvantages, but combustion seems more feasible due to its proximity to current technologies. This is the case with Airbus. The company's flagship sustainability project, ZEROe promises

In aviation, weight is critical. No matter how effective a decarbonization technology is expected to be, it cannot be implemented if it imparts a nonacceptable weight penalty on the aircraft.

a midsized, hydrogen-powered aircraft in service by 2035. Hydrogen can be treated to some extent as a conventional fuel, with the challenge of very low storage temperatures so it can remain liquid. In general, scaling up hydrogen production and the whole supply chain will be very challenging, but hydrogen is three times lighter than kerosene for the same energy content. It also occupies approximately four times more volume, which means that fuel tanks will need to be much bigger for the same range.

Sustainable fuels are here now

The most promising development, particularly for long-haul flying, is the shift that we're just starting to see toward the use of sustainable aviation fuels that require no changes to engines and only minimal adjustments to the supply chain, if any. SAFs can be produced by a variety of methods, but in order not to compete with food crops, companies are focusing on production from waste. The main downside is the current volume of production, which is still thousands of times lower than the actual fuel needs of the industry. There is a long way to go before SAFs become available on a large scale. Environmentally speaking, SAFs result in minimum 80% reduction of life cycle CO_2 emissions, since their production recycles carbon dioxide that was emitted previously and subsequently absorbed from the atmosphere during biomass production. However, there is a remainder of 20% that is not recycled during production and remains in the atmosphere.

A single path may not be necessary

A consideration worth mentioning is that all these different technologies are being developed in parallel, while a major question for airlines is what kind of aircraft they will be called to operate in 15 to 20 years from now. Is there going to be a single, winning technology that will cover all market segments? Or will we see a parallel deployment of different aircraft architectures for the different flight length segments? This question is difficult to answer now. There is no obvious winning technology, and technical consolidation is not expected to happen soon. However, the announcement of national hydrogen strategies during the past year by France, Germany, Japan, the UK and others might favor this type of energy transition for aviation applications.

Another important aspect of this changing landscape is the role of the different governments. The coronavirus crisis acted in some cases as a catalyst for stricter environmental requirements for airlines. For example, the French government supported the national flag carrier Air France with loans during the pandemic but required Air France to scrap all flights competing with the high-speed TGV trains on routes under 2.5 hours. As a result, we might see similar interventions in the future with the aim of accelerating a green transition. What remains to be seen is the impact in the operating models of airlines, since the effect of the different disruptions in aircraft technology, regulations and legislation has the potential of changing the way we travel, favoring multimodality (a combination of different modes of transport) and influencing the way airlines approach ticketing and revenue management.

Taking into consideration the above points, the target of a net-zero output in aviation seems extremely challenging by 2050. The good news is that many in the aeronautical and air transport industry are showing determination to meet the challenges with fundamental changes to their long-established practices. They are supported or in some cases pushed by governments for a solid commitment toward the net-zero 2050 goal. The majority of the technical building blocks that could make zero- or low-emission aircraft feasible for commercial flights are still in low technology readiness levels, sparking a battle against time to improve their maturity. We can never eliminate the risk that not everything will be in place within the intended time frame. Consequently, either a net-zero result or even a 50% reduction by midcentury relies on numerous assumptions. Another important element here is the term "net-zero" itself. It implies that emissions can still be positive but be counterbalanced by carbon offsetting or other carbon removal methods that are being developed. Therefore, a net-zero economy is still achievable with some emissions in place.

Now that the United States and the EU are aligned in their target, it's going to be critical to join forces and share technology and knowledge and form some kind of common vision about the future of the planet. This will allow everyone to work at the same speed in technology development and inspire other nations along the way. The most important objective for every party is to work toward satisfying the Paris Agreement temperature criterion, and there are different paths that can lead to this outcome. ★

Asteris Apostolidis
is a Netherlands-based aviation innovation strategist specializing in sustainable technologies. He has a doctorate in aerospace engineering from Cranfield University and is the innovation strategy manager at Air France-KLM Group. The views expressed in this article are his own and do not necessarily reflect those of Air France-KLM.

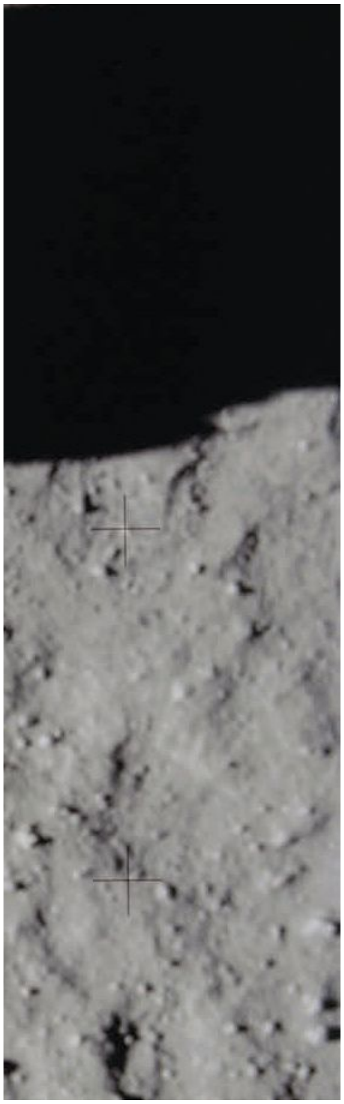

Our Role in Assuring a Cleaner, Greener Future

See "Our Role in Assuring a Cleaner, Greener Future."
PAGE 7

Walking on rocket propellant

Returning to the moon to stay will require making rocket propellant on site, so that crews can rotate back to Earth. As it turns out, mining water ice may not be the fastest or easiest way to produce lunar rocket propellant. Michael Nord of the Lunar Surface Innovation Consortium at Johns Hopkins Applied Physics Laboratory in Maryland explains.

BY MICHAEL NORD



When the world sees America place the next man and the first woman on the moon under the Artemis program, the reaction is likely to be one of immense enthusiasm. Our 1969 landing, with an estimated TV viewership of 650 million, reportedly held the record for the single most viewed human event for 12 years, and there is every reason to expect that in a world much richer with telecommunication, the global reaction will be even greater.

Yet, unfortunately, public interest quickly dropped off after Apollo 11, and six months later the Nixon administration took the first in a series of steps that truncated the Apollo series. How do we convince the White House, Congress and the public that, this time, we will be there to stay? I argue that in-situ resource utilization, or ISRU, is the answer. By operating "gas stations" on the moon that will dispense rocket propellant made in part from lunar oxygen extracted directly from the lunar surface regolith, we will not only lower overall program costs, but also demonstrate the "live-off-the-land" ethic that is immensely popular with the American public and will, likewise, be necessary for going to Mars.

This way, Artemis will become more than Apollo 2.0. We will have shown that we are there to stay.

Our first step toward this, as space professionals, should be to demonstrate to industry and the taxpayers an early and aggressive commitment to ISRU.

So far, we have strong evidence of water at the lunar poles, and this science has increased public and congressional interest in ISRU. The potential availability of large quantities of water ice or hydrated minerals is indeed astonishingly interesting under both a scientific and an economic lens, but there remain significant gaps in our knowledge. We don't know the exact location, distribution or form that the ice may take. Fortunately, NASA will launch a number of spacecraft in the next few years to prospect for water on the moon and narrow those knowledge gaps. Those include PRIME-1, the Polar Resources Ice Mining Experiment-1 lander, and VIPER, the Volatiles Investigating Polar Exploration Rover.

We should vigorously pursue the ISRU path in parallel with prospecting for water. An enormous resource, in fact, lies not just at the poles but on the surface where the Apollo astronauts walked. Oxygen comprises 80% of our rocket propellant needs, and this can be extracted from dry regolith anywhere on the surface of the moon. This is a technological path that will lead to a sustained human presence on the moon. We have enough knowledge to begin planning its extraction now.

Rocket propellant: main driver for ISRU

By mass, the largest consumable at the Artemis base camp will be rocket propellant. Shelters and other infrastructures can be reused. Breathable air and potable water will obviously be critical, but the local production of them is not a large concern. We have ample experience using nearly closed life support systems on the International Space Station. Water is, indeed, precious, but we know how to recycle drinking water — and even air. Rocket propellant, however, is a large resource mass that cannot be recaptured after use.

Dynetics and SpaceX — two of the three providers of human landing systems — have indicated that between 30 and 100 metric tons of propellant may be needed for every return mission from the moon. Compare this with the entire landing mass of an Apollo descent module, which was about 15 tons. Also, recall that the Tsiolkovsky rocket equation is an exponential; to land a single kilogram of propellant on the moon requires at least 80 kilograms of propellant on Earth. This provides a compelling financial and efficiency incentive to produce propellant on the moon. Such a capability will carry us a long way toward sustainability.

Liquid bipropellant rocket fuels

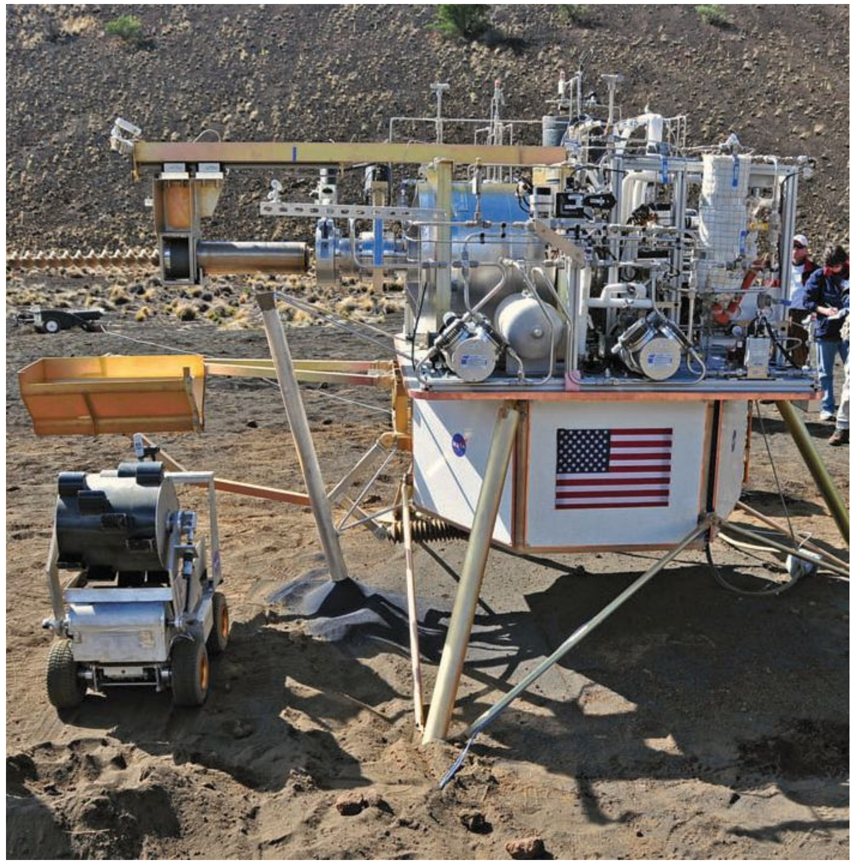
Cryogenic, liquid bipropellant, chemical rocket fuel is comprised of a fuel and an oxidizer. The fuel can be many things — hydrogen, methane, kerosene, even paraffin or powdered aluminum. The oxidizer is nearly always liquid oxygen, or LOX. Usually 70-80% of the mass of rocket propellant before takeoff is LOX. So, how much of these components are available for production on the moon?

We don't expect to find the raw materials for hydrocarbon fuels on the moon. However, we know from the Apollo samples and ground-penetrating radar that the moon has oxygen distributed horizontally across its surface and also vertically to a depth of at least 10 meters. While the exact composition of this regolith is a function of location, no matter where you land on the moon, the regolith beneath you will be 40-45% oxygen, 20-25% silicon, 8-12% aluminum, 5-15% iron and 5-15% calcium, with traces of sodium, potassium, magnesium and titanium. Shortly after Neil Armstrong made his famous small step, he assembled a hand tool and scooped up a "contingency sample" of soil and rock that was stored on board in case he and Buzz Aldrin needed to leave quickly. Armstrong may not have known at the time that 40% of the rock he collected was rocket propellant!

Lunar water knowledge gaps

The craters at the north and south poles of the moon have not seen sunlight in billions of years, and they can be colder than the surface of Pluto. Various

We should vigorously pursue the [on-site resources] path in parallel with prospecting for water. An enormous resource, in fact, lies not just at the poles but on the surface where the Apollo astronauts walked. Oxygen comprises 80% of our rocket propellant needs, and this can be extracted from dry regolith anywhere on the surface of the moon.



▲ **A bucket drum** soil excavator developed by Lockheed Martin delivers soil to the Precursor ISRU Lunar Oxygen Testbed during a NASA field test in Hawaii in 2008. NASA tested lunar rover concepts and how astronauts might make oxygen from lunar rocks and soil.
NASA

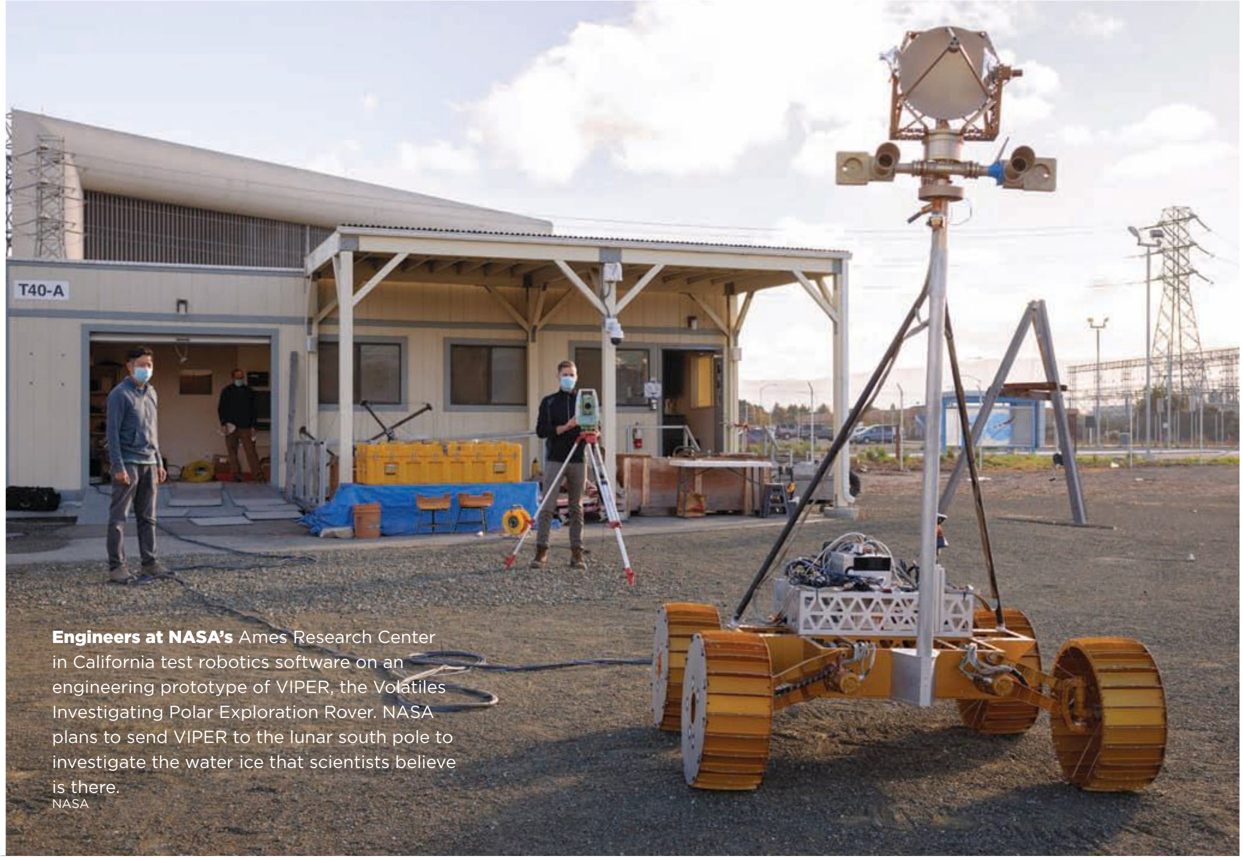
measurements of the moon in recent decades have shown that it's so cold that, even in the vacuum of space, water ice can remain stable. Water is both fuel and oxidizer together in one molecule, so it's tempting to think our problems are solved. Well, not so fast.

While the existence of water on the moon is very exciting, the story is complicated. The permanently shadowed regions on the moon equal an area of approximately 30,000 square kilometers, a little bit smaller than the state of Maryland. We know from orbital neutron spectroscopy measurements that there is hydrogen (from which we infer water ice) within a meter of the surface, and that it's likely under several centimeters of dry soil. We know from one impactor mission to the coldest, darkest and likely "wettest" spot on the moon, that there is definitely water ice, and in that location it's as much as 5% by mass of the lunar regolith. However, the observations suggest the water is not evenly distributed. We know from radar data that most of the ice cannot be in giant slabs, but we don't know how the ice is partitioned among small chunks, tiny grains and surface coatings. Most importantly, we haven't characterized the lateral and depth distribution on the meter-sized spatial scales relevant for ISRU processing. Until PRIME-1 and VIPER land in a couple of years, we will not have a widely accepted theory of its origin and evolution over time, knowledge that would improve predictive modeling of the present-day distribution. Without this information, we rely on educated assumptions for parameters that inform the design of mining equipment. Lack of exactly this type of knowledge contributed to the recent InSight mission's failure to drill into Mars.

Fortunately, preparations are underway to narrow these unknowns. NASA is scheduled to launch the PRIME-1 drill in 2022 and the VIPER mission in 2023 to conduct exploratory drilling for water in a few polar locations, and there are a slew of other small, prospecting satellite missions, either on the books or envisioned for the near future. I welcome these missions, but I am unsure if all, or any, of them will allow us to narrow down locations and develop water extraction equipment and processes inside the 2020s. Extracting oxygen and hydrogen from that water would be one way to produce propellant, but given all the unknowns, establishing the required water plant would require a decade or more of prospecting, design work and space launches.

Rocks to rocket propellant

Here's how we know that separating oxygen from regolith is a practical way of obtaining rocket propellant on the moon. Every day on Earth, silicon, iron, aluminum and other metal oxides are separated into pure metals and oxygen through various processes in refineries around the world. On Earth, the excess oxygen is considered an unwanted, but not harmful, byproduct and is released into the environment. On the moon, the oxygen would be the primary resource to be retained (and the oth-



Engineers at NASA's Ames Research Center in California test robotics software on an engineering prototype of VIPER, the Volatiles Investigating Polar Exploration Rover. NASA plans to send VIPER to the lunar south pole to investigate the water ice that scientists believe is there.
NASA

er metal products would be very useful as well). All that is needed is to capture, purify and store the oxygen. No need to go searching for "gold." No need to remove low-grade soil. No need to have machines operating in the intense cold of the permanently shadowed regions. The entire moon is covered tens to hundreds of meters deep in regolith, and any fistful of lunar regolith is rocket propellant waiting to be processed.

Since the 1960s, scientists and more lately industrialists in the U.S. and abroad have studied various processes for extracting oxygen from lunar rocks. Exactly which process is most efficient, works best with local compositions, has the best throughput and greatest mechanical simplicity and is best suited for operation on the lunar surface are all issues that can and have filled days of impassioned arguments. The bottom line remains the same: 80% of our rocket propellant needs are right there in the regolith, just waiting for us. No prospecting campaign will be necessary for that, but those prospecting missions will close the knowledge gaps and identify the most accessible locations for mining this valuable resource.

Also, there's a bonus to learning to extract oxygen from regolith. The byproducts are silicon and metals. We can expect these resources will be useful later as we start to build solar panels and other structures with material harvested from the moon. We will have to extract these resources eventually. Why not do it now?

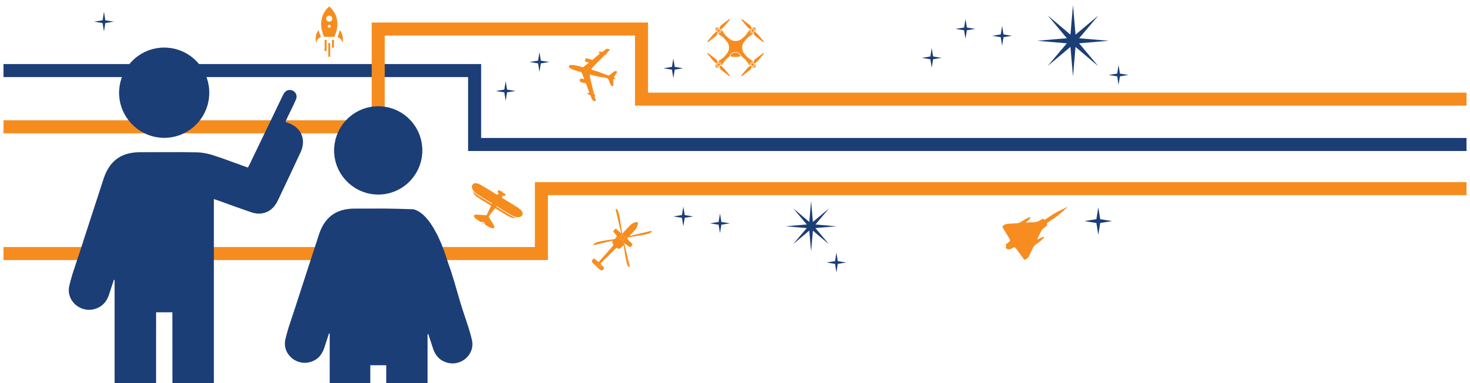
The need for speed

There is no reason to wait until ice on the moon can be effectively extracted. System components for an oxygen-from-regolith system are at a technology readiness level of at least 4 on NASA's nine-level TRL scale, meaning multiple components have been tested in the lab and the field, in this case the volcanic soils of Hawaii. A systems integration and build will need to be completed to test these components in the lunar environment, but NASA, the European Space Agency or, indeed, a commercial entity, could conceivably have a liquid oxygen-from-regolith ISRU pilot plant already running on the moon in 2024 when plans call for the Artemis-3 crew lander to touch down.

Luckily, we can establish the oxygen-from-regolith plant near the lunar south pole, where NASA intends to establish Artemis Base Camp. The lunar poles, in addition to being the location where we think ice is, are also the regions with the maximum available solar power and regions of high scientific interest. It is going to take a lot of power to run either oxygen from regolith ISRU or ice mines. We can emplace the power, communications and oxygen extraction resources now and have it up and running in the near term, all while prospecting for water with robots and astronauts. The ice has been there for billions of years. It will be a few more years before we can find and extract it. Until that day, 80% of our propellant needs are right there in the polar regolith. Let's go get it. ★

Michael Nord is an expert in in-situ-resource utilization at the Johns Hopkins University Applied Physics Laboratory in Maryland.

ENGAGE



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2. ENROLL IN MENTOR MATCH
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AIAA

SHAPING THE FUTURE OF AEROSPACE

AIAA Bulletin

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All AIAA staff can be reached by email. Use the formula first name last initial@aiaa.org. Example: christinew@aiaa.org.

Addresses for Technical Committees and Section Chairs can be found on the AIAA website at aiaa.org.

Other Important Numbers: Aerospace America / Karen Small, ext. 7569 • 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 / Heather Brennan, ext. 7568 • Exhibits and Sponsorship / Paul doCarmo , ext. 7576 • Honors and Awards / Patricia Carr, ext. 7523 • Integration and Outreach Committees / Nancy Hilliard, ext. 7509 • Journal Subscriptions, Member / 800.639.AIAA • Journal Subscriptions, Institutional / Online Archive Subscriptions / Michele Dominiak, ext. 7531 • K–12 Programs / Sha'Niece Simmons, ext. 7590 • 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

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2021			
2–3 Apr	AIAA Region V Student Conference	Iowa City, IA (VIRTUAL)	21 Feb 21
3–4 Apr	AIAA Region VI Student Conference	Long Beach, CA (VIRTUAL)	6 Feb 21
5–9 Apr	AIAA Region II Student Conference	Tuscaloosa, AL (VIRTUAL)	23 Feb 21
6–8 Apr*	AIAA SOSTC Improving Space Operations Workshop	VIRTUAL (https://isow.space.swri.edu)	
6 Apr–13 May	Design of Space Launch Vehicles Course	ONLINE (http://learning.aiaa.org)	
7–16 Apr	Fundamentals of Data and Information Fusion for Aerospace Systems Course	ONLINE (http://learning.aiaa.org)	
9–10 Apr	AIAA Region I Student Conference	New Brunswick, NJ (VIRTUAL)	19 Feb 21
9, 16, 23 Apr	Understanding Space: An Introduction to Astronautics and Space Systems Engineering Course	ONLINE, 3 full days (http://learning.aiaa.org)	
12–14 Apr*	55th 3AF Conference on Applied Aerodynamics (AERO2020+1)	VIRTUAL (http://3af-aerodynamics2020.com)	
13–29 Apr	Fundamentals of Python Programming with Libraries for Aerospace Engineers Course	ONLINE (http://learning.aiaa.org)	
14– 30 Apr	Missile Aerodynamics, Propulsion, and Guidance Course	ONLINE (http://learning.aiaa.org)	
15–18 Apr	AIAA Design/Build/Fly Competition	Tucson, AZ (VIRTUAL)	
20–22 Apr*	Integrated Communication, Navigation, and Surveillance (ICNS) Conference	VIRTUAL (https://i-cns.org)	
21 Apr	ASCENDxWorkshop: Maximizing Payload Success	VIRTUAL (ascend.events)	
5–7 May*	POSTPONED to 2022: 6th CEAS Conference on Guidance Navigation and Control	Berlin, Germany (https://eurognc2021.dglr.de)	
5–28 May	Electrochemical Energy Systems for Electrified Aircraft Propulsion: Batteries and Fuel Cell Systems Course	ONLINE (http://learning.aiaa.org)	
7, 14, 21 May	Foundations of Model-Based Systems Engineering (MBSE) Course	ONLINE, 3 half days (http://learning.aiaa.org)	
18 May	AIAA Aerospace Perspectives Series Webinar: Sustainability	VIRTUAL (aiaa.org/webinars)	
31 May–2 Jun*	28th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (elektropribor.spb.ru/en)	
15 Jun	ASCENDxSummit	VIRTUAL	
21–23 Jun*	3rd Cognitive Communications for Aerospace Applications Workshop	VIRTUAL (http://ieee-ccaa.com)	
23–24 Jun	OpenFOAM CFD Foundations Course	ONLINE, 2 full days (http://learning.aiaa.org)	
24 Jun–13 Jul	Computational Aeroelasticity Course	ONLINE (http://learning.aiaa.org)	

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.).

5–30 Jul	Optimal Control Techniques for UAVs Course	ONLINE (http://learning.aiaa.org)	
20–29 Jul	Digital Engineering Fundamentals Course	ONLINE (http://learning.aiaa.org)	
27–28 Jul	1st AIAA Ice Prediction Workshop	ONLINE (http://learning.aiaa.org)	
2–6 Aug	AIAA AVIATION Forum	VIRTUAL	10 Nov 20
9–11 Aug	AIAA Propulsion and Energy Forum	VIRTUAL	11 Feb 21
11–13 Aug	AIAA/IEEE Electric Aircraft Technologies Symposium	VIRTUAL	
12 Aug	AIAA Aerospace Spotlight Awards Gala	VIRTUAL	
17 Aug	AIAA Fellows Induction Ceremony	VIRTUAL	
6–10 Sep*	32nd Congress of the International Council of the Aeronautical Sciences	Shanghai, China (icas.org)	15 Jul 19
13–15 Sep*	3rd IAA Conference on Space Situational Awareness (ICSSA)	Madrid, Spain (http://reg.conferences.dce.ufl.edu/ICSSA)	15 Jun 21
14–16 Sep	AIAA DEFENSE Forum (Postponed from April)	Laurel, MD	17 Sep 20
28 Sep	ASCENDxSummit	VIRTUAL	
25–29 Oct*	72nd International Astronautical Congress	Dubai, UAE	
15–17 Nov	ASCEND Powered by AIAA	Las Vegas, NV, & ONLINE	30 Mar 21
15–17 Nov	24th AIAA International Space Planes and Hypersonic Systems and Technologies Conference	Las Vegas, NV, & ONLINE	30 Mar 21

2022

3–7 Jan	AIAA SciTech Forum	San Diego, CA	1 Jun 21
7 Jan	3rd AIAA Geometry and Mesh Generation Workshop (GMGW-3)	San Diego, CA	
7 Jan	4th AIAA CFD High Lift Prediction Workshop (HLPW-4)	San Diego, CA	
8–9 Jan	1st AIAA High Fidelity CFD Workshop	San Diego, CA	
19–22 Apr	AIAA DEFENSE Forum	Laurel, MD	
21–24 Jun*	ICNPAA 2021: Mathematical Problems in Engineering, Aerospace and Sciences	Prague, Czech Republic (icnpaa.com)	
25–26 Jun	7th AIAA Drag Prediction Workshop ("DPW-VII: Expanding the Envelope")	Chicago, IL	
27 Jun–1 Jul	AIAA AVIATION Forum	Chicago, IL	

● AIAA Continuing Education offerings

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

2021 Congressional Visits Day

Our 23rd annual Congressional Visits Day program, held virtually 15–19 March, was a huge success with a near-record number of registrants! Approximately 150 members representing 34 states and 31 sections took part, and state teams held virtual meetings with about 200 congressional offices to advocate for the aerospace community. They promoted AIAA's 2021 key issues and called on Congress to support the people and the companies in the aerospace sector by providing adequate funding for programs and missions, increasing investments in research and development, and enabling a diverse ansd robust workforce pipeline. They also explained how the sector is critical for addressing climate change and providing significant opportunity for young people of all races and economic conditions to tackle complex challenges.

We hope to continue this outreach by encouraging our members to invite our elected officials to participate in AIAA section's events and activities and to educate them on issues impacting the aerospace community.

Thanks to all those who participated, and we hope you will join us for CVD 2022.

AIAA Announces Its Class of 2021 Fellows and Honorary Fellows

AIAA has selected its newly elected Class of 2021 Honorary Fellows and Fellows. The induction ceremony for the new Honorary Fellows and Fellows will take place virtually on 17 August 2021.

Honorary Fellow is the highest distinction conferred by AIAA and recognizes preeminent individuals who have had long and highly contributory careers in aerospace and who embody the highest possible standards in aeronautics and astronautics. In 1933, Orville Wright became the first AIAA Honorary Fellow. Today, AIAA Honorary Fellows and AIAA Fellows are the most respected names in the aerospace industry.

The 2021 Honorary Fellows are:

Daniel E. Hastings, *Massachusetts Institute of Technology*
Gwynne E. Shotwell, *Space Exploration Technologies Corporation (SpaceX)*
The Honorable Heidi Shyu, *Heidi Shyu Inc.*

AIAA confers the distinction of Fellow upon individuals in recognition of their notable and valuable contributions to the arts, sciences or technology of aeronautics and astronautics. Nominees are AIAA Associate Fellows. Since the inception of this honor, 1,980 distinguished persons have been elected as a Fellow.

The 2021 AIAA Fellows are:

Juan J. Alonso, *Stanford University*
Randal W. Beard, *Brigham Young University*
Chiara Bisagni, *Delft University of Technology*
Stanley K. Borowski, *NASA Glenn Research Center (retired)*
Chia-Chun "George" Chao, *The Aerospace Corporation (retired)*
Olivier L. de Weck, *Massachusetts Institute of Technology*
Jeanette L. Domber, *Ball Aerospace*
Eric H. Ducharme, *GE Aviation*
Jack R. Edwards, *North Carolina State University*
Richard Scott Erwin, *U.S. Air Force*
Eric M. Feron, *Georgia Institute of Technology*
Irene M. Gregory, *NASA Langley Research Center*
W. Michael Hawes, *Lockheed Martin Corporation*
Michael Keidar, *George Washington University*
Erick Lansard, *Thales*
Roger D. Launius, *Launius Historical Services*
Ivett A. Leyva, *Office of the Deputy Assistant Secretary of the Air Force for Science, Technology and Engineering*
Ioannis G. Mikellides, *NASA Jet Propulsion Laboratory*
Kristi A. Morgansen, *University of Washington*
Greg F. Naterer, *Memorial University*
Daniel I. Newman, *Boeing Defense, Space & Security*
Guillermo Paniagua, *Purdue University*
James E. Polk, *NASA Jet Propulsion Laboratory*
Shahrokh Shahpar, *Rolls-Royce PLC*
Walter A. Silva, *NASA Langley Research Center*
Karen A. Thole, *Pennsylvania State University*
William A. Welsh, *Sikorsky, a Lockheed Martin Company*
Oleg A. Yakimenko, *Naval Postgraduate School*

For more information on the AIAA Honors Program, contact Patricia A. Carr at patriciac@aiaa.org.

2021 AIAA Election Results

AIAA is pleased to announce the results of its 2021 election:

President-Elect
Laura J. McGill
Sandia National Laboratories
Director-Elect–Young Professionals Group
Kaela Martin
Embry-Riddle Aeronautical University
Director–Region III
Peggy A. Cornell
NASA Glenn Research Center
Director–Region VI
Oleg A. Yakimenko
Naval Postgraduate School
Director–Aerospace Design and Structures Group
Jeanette L. Domber
Ball Aerospace & Technologies Corp.
Director–Aerospace Sciences Group
Lesley A. Weitz
The MITRE Corporation

Additionally, the Council of Directors and Board of Trustees held elections for new Board Members-at-Large and Treasurer.

Board of Trustees Member-at-Large
Frank L. Culbertson Jr., *Capt. USN (Ret.)*
R. Steven Justice
Generation Orbit
Todd Mosher
Amazon
AIAA Treasurer
Annalisa L. Weigel
Fairmont Consulting Group

The newly elected will begin their terms of office in May 2021.

Annual Business Meeting Notice

Notice is hereby given that the Annual Business Meeting of the American Institute of Aeronautics and Astronautics (AIAA) will be held on a virtual meeting platform on Monday, 17 May 2021, at 1:00 PM.

AIAA Council of Directors Meeting

Notice is hereby given that an AIAA Council of Directors Meeting will be held on a virtual meeting platform on Tuesday, 18 May 2021, at 1:00 PM.
Christopher Horton, AIAA Governance Director

Recognizing Top Achievements An AIAA Tradition

AIAA is committed to ensuring that aerospace professionals are recognized and celebrated for their achievements, innovations, and discoveries that make the world safer, more connected, more accessible, and more prosperous. From the major missions that reimagine how our nation utilizes air and space to the inventive new applications that enhance everyday living, aerospace professionals leverage their knowledge for the benefit of society. AIAA continues to celebrate that pioneering spirit showcasing the very best in the aerospace industry.

AIAA acknowledges the following individuals who were recognized between October 2020 and January 2021.

Presented at ASCEND, 16–18 November 2020, Virtual Event

2020 von Kármán Lectureship in Astronautics

1 **Thomas H. Zurbuchen**
NASA Headquarters
Lecture Topic: "NASA's Science Program: Civilization Class Science with Societal Benefits"

2020 David W. Thompson Lecture in Space Commerce Award

2 **Charlie Ergen**
Dish Network and Echostar
Lecture Topic: "Transforming a Company in a Changing Industry"

2019 David W. Thompson Lecture in Space Commerce Award

3 **Eddy Hartenstein**
Broadcom Board; Tribune Publishing; DirecTV's; TiVo and Sirius XM Radio
Lecture Topic: "Enabling the Birth and Growth of the Satellite Television Industry"

2020 AIAA Space Systems Award

4 **Bruce Banerdt**
5 **Tom Hoffman**
InSight Flight Team, NASA Jet Propulsion Laboratory
Accepted by Tom Hoffman and Bruce Banerdt
For excellence in development and operations of the InSight mission to Mars, the first mission to explore the deep interior of Mars.

2020 AIAA Space Sciences Award

6 **Cold Atom Laboratory Team**

Accepted by: Robert J. Thompson, NASA Jet Propulsion Laboratory, and Eric Cornell, University of Colorado

For developing and delivering the highly innovative Cold Atom Laboratory to the ISS and for seminal scientific achievements.

2020 AIAA von Braun Award for Excellence in Space Program Management

7 **Parker Solar Probe Program Management Team**

Johns Hopkins University Applied Physics Laboratory

Accepted by: Andy Driesman, Patrick Hill, and Kim Cooper

For a daunting science mission that demanded exceptional program management skills to balance science requirements, budgets and launch window, and engineering development.

Presented at AIAA SciTech Forum, 11–15 & 19–21 January 2021, Virtual Event

2019 John Leland Atwood Award

8 **Byron D. Tapley**

University of Texas at Austin

For the lasting influence of his recent contributions to aerospace engineering education.

2021 Durand Lectureship for Public Service

9 **David W. Thompson**

Orbital ATK, Inc. (retired)

Lecture Topic: "The History and Prospects of Commercial Space Activity"

2021 AIAA Children's Literature Award

10 **Billie Holladay Skelley**

Author, Goldminds Publishing, Amphorae Publishing

Ruth Law: The Queen of the Air

2021 Gardner-Lasser Aerospace History Literature Award

11 **Slava Gerovitch**

Massachusetts Institute of Technology

Soviet Space Mythologies: Public Images, Private Memories, and the Making of a Cultural Identity

2021 Pendray Aerospace Literature Award

12 **Tim C. Lieuwen**

Georgia Institute of Technology

For outstanding contributions to the development of aerospace literature in combustion and propulsion, particularly in unsteady combustor physics, gas turbine emissions, and synthesis gas combustion.

2021 AIAA Summerfield Book Award

13 **John D. Anderson**

National Air and Space Museum, Smithsonian Institution

Hypersonic and High-Temperature Gas Dynamics, Third Edition

2021 AIAA Diversity and Inclusion Award

14 **Dexter Johnson**

NASA Engineering and Safety Center, NASA Langley Research Center

For your significant contributions to advancing diversity and inclusion within the aerospace and astronautics community through your AIAA collaborations with students and industry partners.

2020 AIAA Multidisciplinary Design Optimization Award

15 **Raymond M. Kolonay**

Air Force Research Laboratory (AFRL)

For visionary leadership in the MDO community and development of nonlinear unsteady aeroelastic optimization methods and collaborative/distributed architectures enabling large-scale multidisciplinary aircraft design.

2020 AIAA Propellants & Combustion Award

16 **Meredith B. Colket III**

United Technologies Research Center (retired)

For pioneering contributions in the development of endothermic fuels leading to demonstration of the X-51 and coordinating technology programs supporting certification of alternative jet fuels.

2021 AIAA-ASC James H. Starnes Jr. Award

17 **David Bushnell**

Lockheed Martin Corporation (retired)

For pioneering contributions to the analysis and design of thin-shell structures and enduring leadership in the application and preservation of that knowledge for future generations.

2021 AIAA Ashley Award for Aeroelasticity

18 **Eli Livne**

University of Washington

For carrying out foundational works for aeroservoelastic optimization; leadership in maturing active flutter suppression to practice, and for major contributions to dissemination of aeroelastic knowledge.

2021 AIAA Information Systems Award

19 **Erik P. Blasch**

Air Force Office of Scientific Research

For technical leadership and innovation in information fusion systems for avionics, space situational awareness, and airborne sensing.

2021 AIAA Mechanics and Control of Flight Award

20 **Fred Y. Hadaegh**

NASA Jet Propulsion Laboratory

Extraordinary contributions for advances in the theory, computation, and implementation of autonomous guidance, navigation, and control of single and distributed spacecraft systems.

MAKING AN IMPACT

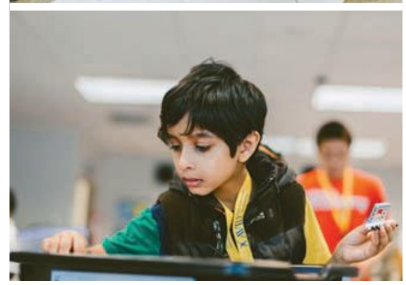
AIAA Partners with AVID to Make Educational Resources Available

AIAA and AVID (Advancement Via Individual Determination) has partnered to create a no-cost educational resource called AVID Open Access (AVIDopenaccess.org) that contains high-quality grab-and-go lesson plans, student activities, and teacher resources to bring STEM into any classroom. The site has generated great interest in the educator community with over 120,000 visitors since its launch in late spring 2020.

AVID Open Access provides educators with collections that address timely topics throughout the school year, from setting up a digital classroom to designing online lessons with equity, diversity, and inclusion in mind, to meeting students' social and emotional needs during remote and hybrid learning. AVID Open Access has explored such topics as project-based learning in online environments, building students' digital study skills, and how to model digital citizenship and mindfulness for all. Every two weeks, AVID Open Access provides new collections containing strategies, best practices, and tech tips that teachers can immediately apply in their classroom.

In addition to the lesson resources, AVID Open Access offers a podcast for educators, Tech Talk for Teachers, this podcast aims to help you transform today's students into tomorrow's empowered digital learners. We provide immediately applicable digital strategies and tech tips during engaging, down-to-earth conversations that address the challenging topics we are facing in our classrooms today.

Help us to continue supporting educators with a gift to the AIAA Foundation. Donate today: **aiaa.org/foundation.**



News

AIAA Charters New Student Branches

AIAA is excited to announce the addition of two new AIAA student branches at Embry-Riddle Aeronautical University Worldwide (ERAU-Worldwide) and the University of Georgia (UGA). These universities join more than 240 AIAA student branches around the world.

Both universities are distinctive additions to AIAA's student branch community. **ERAU-Worldwide's** fully online program is ranked No. 1 by *U.S. News & World Report* for its online bachelor's degree programs. The AIAA ERAU-Worldwide Student Branch is under the College of Aeronautics, whose programs emphasize interaction with aerospace professionals and organizations. **UGA's** College of Engineering offers undergraduate and graduate degrees in mechanical, computer systems, and electrical engineering programs. Its AIAA student branch will fit in UGA's Student Aerospace Initiative, which engages the student body in real-world multidisciplinary aerospace projects.

AIAA's student branches include 40+ international student branches and a total active membership of over 7,500 students worldwide. If you are interested in forming an AIAA student branch, begin the process at **aiaa.org/get-involved/students-educators/Student-Branches**.

HRS Members Volunteer at FIRST Lego League

By Karen Berger, AIAA HRS K-12 Outreach Co-Chair

In a year where everything seems a little (or a lot) different, FIRST Lego League was no exception. Teams and organizers had to figure out how to run a competition with the new Covid-19 restrictions. Some school teams never actually met each other face to face throughout the entire season. For the tournaments, everything moved to a remote, online environment while trying to recreate as much of the experience as possible.

Still, an amazing 120 teams choose to compete in Virginia/DC, participating in 8 regional tournaments that were run from 23 January to 7 February. The top 64 of those teams also competed in the VA-DC FLL Championship tournament on 27 February.

This year's theme was RePLAY and it was about getting kids and entire communities healthier and more active. Whether it was finding new ways to utilize outdoor space to spending more time in sports to just getting up and dancing, teams challenged themselves to tackle this real-world problem as a part of their Innovation Project. Additionally, their robots autonomously earned points for completing the robot game challenges like using the step counter, playing basketball, dancing, and doing pullups.

AIAA Hampton Roads Section members helped at a number of the tournaments, filling roles at events across the state. Vanessa Aubuchon, Linda Bangert, Carol Bauer, Steve Bauer, Karen Berger, Michael Bozeman, Amanda Chou, and Andrew Lovejoy served in critical roles as head judges, head referees, judges, and referees. The coaches were especially appreciative this year of the volunteer effort to give these students a great experience in such a crazy year. A few comments from them include:

"I wanted to congratulate you all on a great competition today. I got to sit in on my team's interview andit was fantastic. The people that asked the questions and helped the students along with their answers wereas professional as they were kind and it was wonderful. I just wanted you to know that and have a great day" – Coach of multiple teams

"To the VA-DC FLL team, You all continue to impress. Today's tournament from this coach's point of view went flawlessly. It couldn't have been easy, but you sure made it look that way. Kaitlin, Karen, Scott, and Steve, and judges, refs, and all of the other volunteers: thanks! My team had a great time, and this was very much worth the effort you put into it. Now just do it again, what, ten more times??? :)" – Team Coach

Creating the JSF Lecture

By Charlie Svoboda, Education Officer, AIAA St. Louis Section

On 19 January a virtual presentation entitled "Creating the JSF" was given by Paul Bevilaqua. This presentation was jointly sponsored by the AIAA St. Louis Section and the Vertical Flight Society (VFS), and targeted both professional and student members of both organizations. Over 38 attendees participated in the presentation and question-and-answer session. One of the interesting parts of the Joint Strike Fighter story is how the program was developed. Originally the plan was to develop the Marine configuration only, but after an Air Force general saw the presentation an Air Force version was proposed.

The St. Louis Section is investigating the development of a STEM-tailored version of the presentation with Dr. Bevilaqua and may offer that to high school and middle school students in the St Louis area. We also plan to have another joint AIAA and VFS presentation about the V-22 Osprey in May.

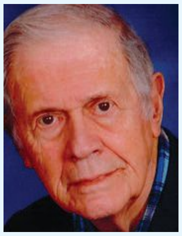
AIAA Associate Fellow Eldon Knuth Awarded Bronze Star

In fall 2020, AIAA Associate Fellow **Eldon Knuth**, 95, was honored for his service during World War II when he was presented with the Bronze Star. In November 1944, he and about 30 soldiers from the U.S. Army's 95th Infantry Division became stuck for five days behind enemy lines near the French city of Metz. The group of survivors became known as the Iron Men of Metz and at a reunion of the survivors in 2019, Knuth also was awarded the French National Legion of Honor Medal.

Knuth went on to complete his Ph.D. in aeronautics. After working for companies that developed equipment for the U.S. space program, including rocket motors and heating problems for space vehicles, he returned to academia and taught for 35 years as a chemical engineering professor at the University of California, Los Angeles. He is also the author of more than 100 technical papers.

Obituaries

AIAA Honorary Fellow Sutton Died in February



George Sutton – an eminent engineer and scientist and the longest serving editor-in-chief of the *AIAA Journal* – passed away on 13 February. He was 93.

Dr. Sutton served in the United States Merchant Marine during World War II and the Army Air Force in Okinawa through 1947. He graduated with honors from Cornell University's School of Engineering in 1952 and received his Master of Science and Ph.D. in Engineering and Physics (magna cum laude) from the California Institute of Technology (Caltech) in 1955.

Dr. Sutton, an expert in heat protection material for hypersonic flight, magnetohydrodynamics, and high-power lasers, taught at Stanford University, the University of Pennsylvania, and MIT.

As an engineer and scientist, Dr. Sutton made many significant and impactful contributions in aerospace. These contributions included being the first to measure the heat transfer in the throat of a rocket nozzle; invention of the ablation heat shield material, used by U.S. ICBMs and early manned space flight; production of the first resolved photograph of a foreign spacecraft from AMOS telescope in Hawaii; development of the concept design for the first high power CO_2 laser that generated 130 kW; demonstration of the small high frequency transcutaneous energy supply for artificial hearts used by Abiomed; and development of the concept design of the SOFIA aircraft for infrared astronomy and aero-optic analysis of the airflow.

His impact on the *AIAA Journal* remains an unmatched legacy. As the editor-in-chief of the *AIAA Journal*, Dr. Sutton wanted each article to have relevance to aerospace. From 1967 to 1996, the *AIAA Journal* disseminated an enormous amount of knowledge that nurtured and advanced aerospace engineering. Dr. Sutton also coauthored three books, authored 130 technical papers, and held eight patents.

His accomplishments have been recognized with numerous awards, including the Arthur S. Flemming Award (1965) for "unique contributions to the fields of heat protection of hypersonic re-entry vehicles, and magnetohydrodynamic power generation," the AIAA Thermophysics Award (1980), the AIAA Distinguished Service Award (1988), and the AIAA Plasmadynamics and Lasers Award (2007). He was also a member of the National Academy of Engineering and the National Research Council.

AIAA Senior Member Grafton Died in July 2020

John C. Grafton died on 19 July 2020 at age 89.

He graduated from the University of California, Los Angeles with an engineering degree. For 36 years Grafton worked at North American Aviation, later Rockwell International Aerospace, on the Apollo Missions and on the Global Positioning System.

AIAA Senior Member Buss Died in November 2020

Randall D. Buss, 62, passed away of Covid-19 on 17 November.

Buss earned a degree in Mechanical Engineering from the University of Illinois. He worked as an engineer at the Cordova Nuclear Power Plant and later as a Root Cause Analyst at nuclear power plants in numerous states. He was a very enthusiastic member of the National Space Society, always attending their annual International Space Development Conferences.

AIAA Senior Member Phillips Died in November 2020

Roy B. Phillips died on 17 November; he was 84 years old.

Phillips went to the University of Minnesota and earned a degree in aeronautical engineering. He earned advanced degrees from the University of Cincinnati, the University of Southern California, and the University of Washington.

Phillips took a job with the Boeing Company, where he would work in a number of capacities while traveling the world for forty years until his retirement in 2001.

AIAA Senior Member Feo Died in November 2020

Alejandro (Alex) Feo Palacios died in November 2020. He was 79 years old.

Dr. Feo graduated as an aeronautical engineer from the Escuela Técnica Superior de Ingenieros Aeronáuticos (ETSIA) in Madrid, Spain. He pursued graduate studies at the University of Michigan where he obtained M.S. and Ph.D. degrees in Aerospace Science in 1967 and 1970. He continued postdoctoral studies at ETSIA and was awarded the degree of Doctor Ingeniero Aeronáutico in 1978.

He joined the Instituto Nacional de Técnica Aeroespacial (INTA) in Madrid in 1971 and worked there throughout his career. Dr. Feo was named head of the Experimental Aerodynamics Department in 1994 and held that position until his retirement in 2011. His scientific and technical contributions were rewarded with the prestigious Spanish Cross of Aeronautical Merit (White Badge).

During his 50-year career, Dr. Feo made numerous contributions to the atmospheric sciences as applied to the advancement of aeronautics and astronautics, most significantly in the field of aircraft safety in the areas of heavy rain effects on the aerodynamics of aircraft, aircraft icing, icing scaling, and icing physics. He was the Principal Investigator under a Joint Program between INTA and NASA Langley Research Center from 1984 to 1994, responsible for designing and conducting experimental work at INTA. There, he developed an innovative Rotating Arm Facility for advanced studies of droplet impact and splashing that allowed measurement and visualization of single drop impact characteristics for drop sizes and velocities representative of values encountered in flight.

Dr. Feo is one of the major contributors to the development of icing scaling methods. He conducted aircraft icing and icing physics studies at INTA from 1995 to 2010, part of a collaborative research program between INTA and NASA Glenn Research Center. His research centered on icing scaling and droplet break up near the leading edge of airfoils.

In 2008, under Dr. Feo's initiative and leadership, INTA participated in the European project EXTICE. He was appointed as INTA's coordinator for the project, and the results had a strong impact on the numerical calculation of droplet trajectories in European icing codes. From 1994 to 1997 he worked with AGARD Working Group (WG-20) on "Ice Accretion Simulation," covering the status of analytical and experimental research of heat transfer coefficient measurements. In February 1997 he was one of the lecturers who presented an extended version of the publication in a special course held at the Von Karman Institute for Fluid Mechanics. Dr. Feo represented INTA as member of the NATO/RTO AVT-006 Working Group on "Ice Accretion Evaluation" from 1998 to 2000. In 1999, he was appointed by GARTEUR (European Group of Aeronautical Research and Technology) to chair the Action Group AG-32 on Airfoil Performance Degradation Due to Icing. This position lasted until 2003 and was later extended from 2006 to 2010 as AG-40. He also participated as a member of AG-33 on Ice Accretion contributing with a chapter on icing scaling methods.

In 2012, Dr. Feo was awarded the AIAA Losey Atmospheric Sciences Award for his exceptional research contributions and international scientific leadership on icing scaling, icing physics, heavy rain effects on the aerodynamics of aircraft and the development of advanced research facilities.

AIAA Senior Member Winglee Died in December 2020

Professor Robert M. Winglee, died on 24 December. He was 62 years old.

Professor Winglee graduated from the University of Sydney in 1985 with a Ph.D. in Physics. As a professor in Earth and Space Sciences (ESS) at the University of Washington, his passion was teaching students and doing research in space plasmas, engineering, and space environments of planets. His encouragement of his students led to many innovative concepts that continue to be spread throughout the space industry. His research efforts were featured on the Discovery Channel *Science of Star Wars* (2005) and *Mars Rising* (2007). He was a Fellow of NASA's Innovative Advanced Concepts. He served as Chair of ESS from 2005 to 2015, and was the recipient of the 2001 DISCOVER Magazine Awards for Technological Innovation, and the 2014 UW Undergraduate Research Mentor of the Year. He accomplished his dream of going into space when he launched a student-built and designed miniature satellite (CubeSat), which successfully transmitted data from orbit.

One of his proudest recent achievements was founding the Northwest Earth and Space Sciences Pipeline (NESSP) in order to bring STEM to underrepresented and minority students. Through his directorships of Washington NASA Space Grant and NESSP, he touched the lives of many middle and high school students throughout the country. When students saw him coming, they would yell out, "Here comes the rocket man!"

AIAA Associate Fellow Niemi Died in December 2020

Eugene E. "Gene" Niemi Jr. died 25 December. He was 81 years old.

As a youth, he was a member of the volunteer Ground Observer Corps doing aircraft spotting, and the Civil Air Patrol, where he achieved the rank of Cadet Major. He spent summers at Fitchburg Airport, which led to his love for flying. Niemi received a bachelor's degree in aeronautical engineering from Boston University, a master's degree in mechanical engineering from Worcester Polytechnic Institute, and a Ph.D. in mechanical and aerospace engineering from the University of Massachusetts Amherst.

Niemi was a professor of Mechanical Engineering at the University of Massachusetts Lowell since 1966. Before that, he worked as an engineer at General Electric Company designing steam turbines and at Raytheon Company Missile Systems Division working on missile aerodynamics.

At UMass Lowell, Niemi taught courses in aerodynamics and flight mechanics, ocean engineering, fluid mechanics, thermodynamics, and heat transfer. During summers he worked in industry and research at such places as NASA in Virginia and California, the U.S. Air Force in Tennessee, and the U.S. Army Natick Research Labs in Massachusetts. At the time of his death, he was writing a textbook on aerodynamics.

Having joined AIAA in 1984, Niemi was a long-time supporter of the New England Section, serving on the section council and also as the faculty advisor for the AIAA UMass Lowell Student Branch (2007–2011). He was an avid pilot with a commercial license and instrument rating, at one time owning his own airplane. In his earlier years, he was also a gyrocopter pilot, often flying demonstration flights at the Fitchburg and Gardner airports and airshows in New England.

AIAA Associate Fellow Owczarek Died in January

Jerzy A. Owczarek, 94, professor emeritus of mechanical engineering and mechanics at Lehigh University, died on 11 January.

Born in Poland in 1926, Owczarek fought against German occupying forces during World War II as a member of the Polish Home Army (AK), and lost sight in his left eye after he was wounded. In 1945, he was able to enroll at the Mining Academy in Krakow before his studies were abruptly halted in 1946, when he and a large number of fellow students were arrested for staging an anti-communist demonstration. After a short time in prison, Owczarek escaped the country and made his way to Italy, where he joined the 2nd Polish Corps of the British 8th Army in Ancona. A few months later, he was transported to England.

Resuming his studies at the Polish University College in London, Owczarek received a Dipl.-Ing. degree in Mechanical Engineering in 1950 and went on to graduate studies at the University of London. He received a Ph.D. in Mechanical Engineering in 1954 and soon after moved to the United States where he acquired a position in the Turbine Division of the General Electric Company in Schenectady, NY.

Owczarek joined Lehigh University as an associate professor in 1960, became a full professor in 1965, and retired in 1995. He was awarded an Outstanding Faculty Award by the Tau Beta Pi Engineering Honorary Society in 1979, and named Mechanical Engineering Teacher of the Year by the Pi Tau Sigma Mechanical Engineering Honorary Society in 1993.

Owczarek was the author of two books: *Fundamentals of Gas Dynamics* (1964) and *Introduction to Fluid Mechanics* (1968). His research in the fields of gas dynamics, turbomachinery, fluidics, and rheology also resulted in 26 journal articles and 40 technical reports. From 1969 to 1973, he directed a Themis Project on Fluid Amplifiers at Lehigh; from 1990 to 1994 he collaborated on the design, building, and operation of the Gas Dynamics Laboratory at Lehigh's Mountaintop Campus. He was a consultant to numerous industrial firms, notably Bell Laboratories and DeLaval Turbine Inc. Owczarek filed seven patents dealing with turbomachines, steam turbines, and gas turbines. He belonged to several professional organizations, including AIAA and ASME.

CONTINUED FROM PAGE 64

Unfortunately, our current scientific culture does not adequately value transdisciplinarity and those who seek to practice it. For this to change, academia must sow and nurture the concept, for instance, by permitting a dual degree in government and engineering. Likewise, industry must see value in those graduates with this training.

As an example, let's look at trying to mitigate an orbital collision between a pair of satellites. A solution may need the following: (a) someone who studies the space weather and environment, (b) an astrodynamicist who understands how this space weather influences the motion of objects in space, (c) an orbit determination analyst who understands the astrodynamics and can take sensor data gathered on these objects to infer their statistical trajectories, (d) a space lawyer who knows the general rules the satellite operators might be subject to in defining their liability if damage were to occur, (e) a social scientist who can provide cultural context to how the satellite operators might interpret a common space law or policy, and more. There are no naturally occurring situations under which this group of experts spanning disparate disciplines would likely assemble and work concurrently on a transdisciplinary solution.

To be sure, transdisciplinarians will unlikely reach the technical depths of the stove-piped scientist or lawyer or policymaker, but they don't need to. Transdisciplinarians will be able to synthesize concurrent multidisciplinary inputs and will have sufficient expertise in several of them to know how to execute, guide and direct solutions to a meaningful conclusion. Although transdisciplinarians have yet to be globally embraced, I'll continue to identify them and work on creating a welcoming and nurturing home for these unsung superheroes of the Renaissance Encore. ★

Our current scientific culture does not adequately value transdisciplinarity and those who seek to practice it.

LOOKING BACK

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1921

April 1 The Australian Air Force is formed from the Australian Air Corps. It will become the Royal Australian Air Force in August. David Baker, **Flight and Flying: A Chronology**, p. 138.

April 14 After smuggling its factory across the German border into the Netherlands at the end of World War I, Fokker turns to building a series of new advanced commercial transports and delivers its latest Fokker F.III monoplane airliner, a five-seater, to KLM, Royal Dutch Airlines. David Baker, **Flight and Flying: A Chronology**, p. 138.

1 **April 14** The Davis-Douglas Co. receives its first contract, from the U.S. Navy, for three DT-1 biplane torpedo bombers. It is the first military contract for what will become Donald Douglas' Douglas Aircraft Co. Rene J. Francillon, **McDonnell Douglas Aircraft Since 1920**, p. 23.

April 27 The first non-rigid airship built for Japan is test flown for the first time by its builder, the British firm of Vickers Ltd., at Barrow, England, with Japanese officers aboard. **Flight**, May 5, 1921, p. 317.

During April 1921 British Controlled Oil Fields Co. begins an expedition to prospect for oil by aircraft in Venezuela. Maj. Cochran Patrick leads the trip accompanied by two pilots flying specially fitted Supermarine flying boats. The operation includes riggers, fitters and an expert aerial photographer with an L.B. type aerial camera for taking detailed photos to be examined for likely geological sites for oil. **Fligh**t, March 31, 1921, p. 225.

1946

2 **April 1** The U.S. Army Air Forces awards Bell Aircraft a contract under Project MX-776 for air-to-surface subsonic guided missiles, each with a range of 160 kilometers. They later become known as Rascals, with a 480-kilometer range. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 53.

April 8 Changi Airport, 22 kilometers from Singapore and the biggest airfield in the Far East, is opened by Air Chief Marshal Sir Keith Park, Allied (British) air commander in chief. The field was partly built during the Japanese occupation by Australian and British prisoners of war and completed by Japanese POWs after the liberation. **The Aeroplane**, April 19, 1946, p. 450.

April 16 A 43-seat Lockheed Constellation flown by Panair of Brasil Airlines becomes the first plane of a foreign airline to land at London Airport (Heathrow). The aircraft is also the first of three Constellations ordered by Panair and the first Constellation to land at the airport. Panair do Brasil was formed as a subsidiary of Pan American Airways, and in 1944 control of the company was transferred to Brazil. **The Aeroplane**, April 26, 1946, p. 499.

April 22 The U.S. Army Air Forces grants a contract to the Glenn L. Martin Co. for MX-771 surface-to-surface missiles, later designated the Matador. Each swept-wing, near-supersonic missile will be powered by an Allison J33 turbo jet for the sustainer engine in addition to a large solid-fuel booster. The 965-kilometer-range Matadors become operational in 1954. K.W. Gatland, **Development of the Guided Missile**, pp. 264-265.

April 24 The Mikoyan MiG-9 fighter becomes the Soviet Union's first pure jet to fly. The I-300 prototype is powered by twin RD20 engines, which provide a top speed of 900 kph. The RD20s are based on the BMW 003 turbojet. Later in the day the diminutive Yakovlev Yak-15 jet fighter also flies for the first time. David Baker, **Flight and Flying: A Chronology**, p. 309.

1971

3 **April 6** Intelsat-1, also known as the Early Bird, is reactivated in its geosynchronous orbit over the Pacific, and to mark its sixth anniversary it relays the first message ever transmitted via a commercial satellite directly from Hawaii to the East Coast of the U.S. Built by the Space and Communications Group of Hughes Aircraft Co. for COMSAT, Intelsat-1 was the first commercial communications satellite to be placed in geosynchronous orbit on this date in 1965. Among other milestones, the 34.5-kilogram satellite helped provide the first live TV coverage of a spacecraft splashdown, that of Gemini 6 in December 1965. **ComSatCorp Release 71-23**.

4 5 **April 14** Armand Spitz, an astronomer and author who organized NASA's Moonwatch Program of volunteer astronomers to track satellites early in the space program, dies at 66. Spitz also created the Spitz planetarium projector, a small teaching tool for schools and small museums. The company he founded continues to produce planetariums and domes for companies and institutions such as Disney, Universal Studios and Griffith Observatory. **Washington Star**, April 16, 1971, p. B5.

April 19 The Soviet Union launches its uncrewed Salyut-1 orbital scientific station from the Baikonur Cosmodrome and it becomes the first operational space station. **Baltimore Sun**, April 20, 1971, p. A1, and Oct. 16, 1971, p. A-3.

April 23-25 The Soviet Union's Soyuz 10 carrying cosmonauts Vladimir Shatalov, Aleksey Yeliseyev and Nikolai Rukavishnikov is launched from Baikonur Cosmodrome; it is designed to link up with the uncrewed Salyut-1 space station. The spacecraft make contact without a full link on April 24, and the crew returns to Earth without having entered the station. **New York Times**, April 23-26, 1971.

April 14 Italy's San Marco-3 satellite is launched by a U.S. solid-propellant Scout booster from a platform off the coast of Kenya. The primary objective of the 171.5-kilogram satellite, the third satellite launched under a 1962 agreement between NASA and the Italian Space Commission, is to carry out atmospheric density studies. NASA, **Astronautics and Aeronautics, 1971**, pp. 109-110.

6 **April 28** NASA announces its discontinuation of quarantines for Apollo astronauts after they have flown to the moon for the remaining three Apollo flights. The decision is made after a review in which it is determined that there is no hazard to humans, animals, or plants in the lunar material brought back from the moon. NASA, **Astronautics and Aeronautics, 1971**, p. 115.

1996

April 1 The space shuttle Atlantis crew completes a nine-day mission, landing the spacecraft at Edwards Air Force Base in California after weather conditions precluded landing in Florida. NASA, **Astronautics and Aeronautics: A Chronology, 1996-2000**, p. 13.

7 **April 9** NASA flies its Lockheed ER-2 high-altitude reconnaissance aircraft, which is based on the U-2 spyplane, to survey damage caused by the leak of toxic chemicals from the California Gulch Superfund Site in Leadville, Colorado. Images taken by cameras and spectrometers on the plane cover hundreds of square kilometers. NASA, **Astronautics and Aeronautics: A Chronology, 1996-2000**, p. 14.

April 9 For the first time, a Western-built satellite, the Astra IF, is launched by a Soviet Union rocket, the Proton heavy lift vehicle. The Astra IF was built by the Hughes Space and Communications Co. for Luxembourg's Société Européene des Satellites and placed in geostationary orbit to provide direct TV and radio broadcasts. **Aviation Week**, July 22, 1996, p. 5.

8 **April 23** The last major section of the Mir space station is launched into orbit from the Baikonur Cosmodrome in Kazakhstan. The 21-ton Priroda module is designed as a laboratory and is fitted with scientific equipment for use by American astronaut Shannon Lucid. NASA, **Astronautics and Aeronautics: A Chronology, 1996-2000**, pp. 16-17.

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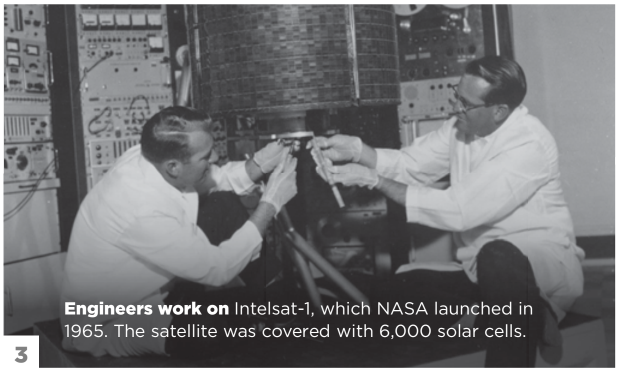


3

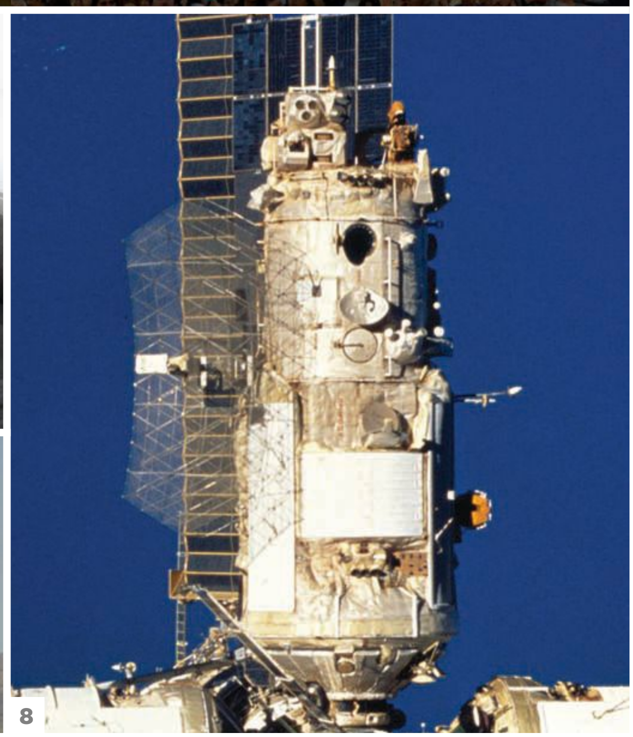
Engineers work on Intelsat-1, which NASA launched in 1965. The satellite was covered with 6,000 solar cells.

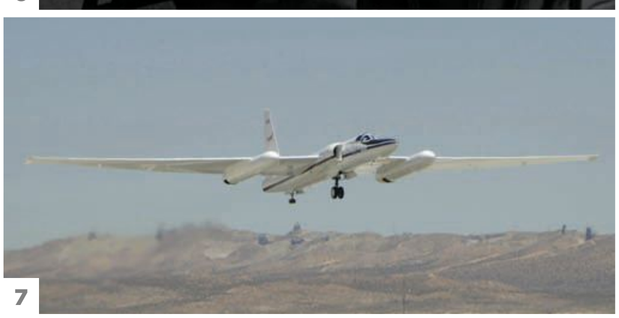
4 5

A Spitz projector at a planetarium in Montevideo, Uruguay. Fedaro/Flickr

6

NASA astronauts, from left, Buzz Aldrin, Michael Collins and Neil Armstrong share a meal while under quarantine at NASA's Johnson Space Center in Houston after their 1969 Apollo 11 lunar mission. In 1971, NASA discontinued the requirement that Apollo astronauts must quarantine after returning from the moon.





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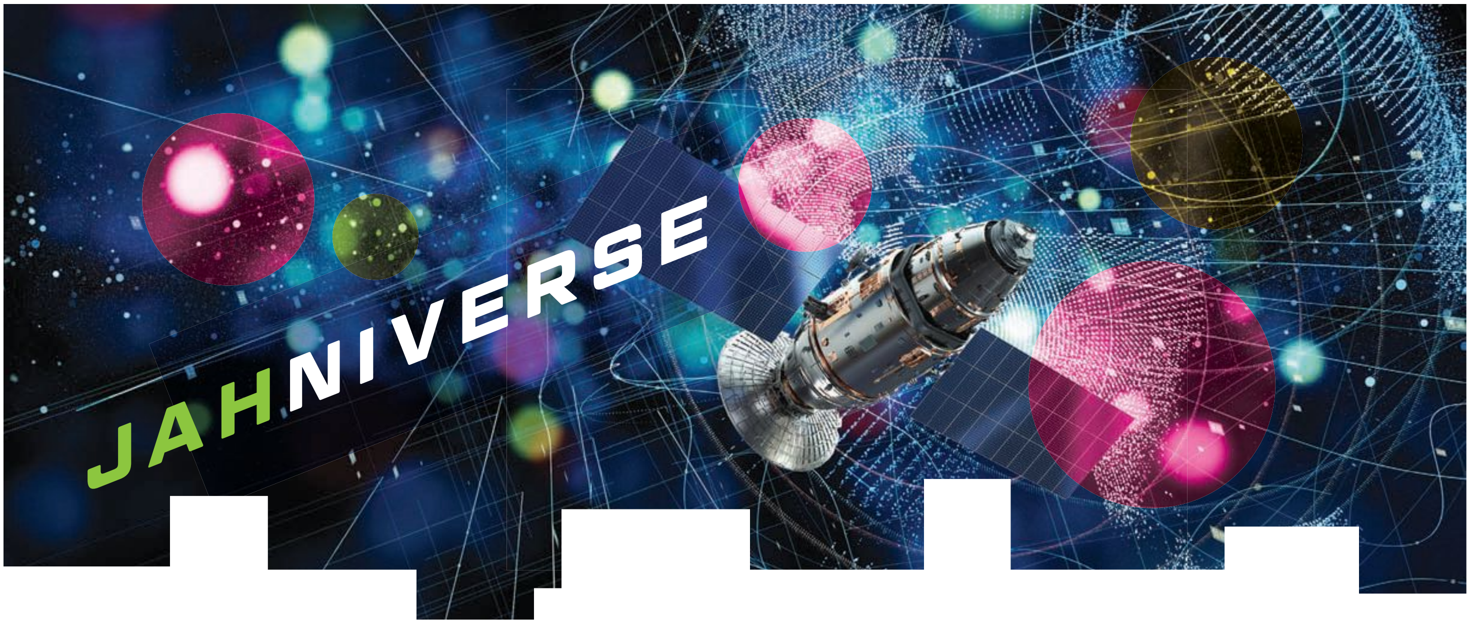

Meet your next-generation superheroes

BY MORIBA JAH

A new scientific revolution, let's call it the Renaissance Encore, is gestating after being conceived by transdisciplinarity, a holistic fusion of seemingly unrelated professional specialties across disciplinary boundaries.

You'll recognize a transdisciplinary solution when you struggle to identify the individual disciplinary contributions to it. The main driver behind the Renaissance Encore is the need to solve wicked problems, meaning those that can't be solved in the traditional ways due to contradictory information, incomplete data and competing interests.

Keeping order in the near Earth space environment is a great example of a wicked problem. The behavior of constituents, such as satellite owners and operators, are difficult to model and predict. We don't know, for example, how a particular company or agency would react to a given hazard or odds of a collision. Some might order evasive action; others might stay put. An aerospace engineer alone couldn't solve that problem.

While transdisciplinarity is gestating, most folks in the space community still tend to stay within their respective disciplines and educational or job comfort zones. Until we change that, we won't be able to solve the space domain's wicked problems. This tendency of researchers and workers to stay within a specific discipline is a remnant of the original Renaissance that began in the 14th century. Sir Isaac Newton focused mainly on mathematics and physics, developing what we know as calculus and coming up with laws of physical motion. In order to achieve this, he didn't need to practice law or be an anthropologist. Galileo Galilei performed gravity experiments at the tower of Pisa and subscribed to a heliocentric view of planetary motion, a conclusion he could reach just by staying within his discipline. In fact, for the most part, the changes in societal views during the Renaissance, such as Earth's place in the cosmos, came as a consequence of developments in and a convergence of specific disciplines, rather than through transdisciplinarity.

In the space domain, embracing transdisciplinarity would require managers to be well rounded. They must be willing to reach across disciplinary boundaries to bring in experts on everything from astrodynamics to space law and policy. From the outside, such disciplines may seem to be mutually orthogonal, but in the context of solving a wicked problem, they are linked.

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. He holds the Mrs. Pearlie Dashiell Henderson Centennial Fellowship in Engineering and is an AIAA fellow. He also hosts the monthly webcast "Moriba's Vox Populi" on SpaceWatch.global.


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