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MIT's ion aircraft

AUTONOMY 18
Inside DARPA's midair drone recovery

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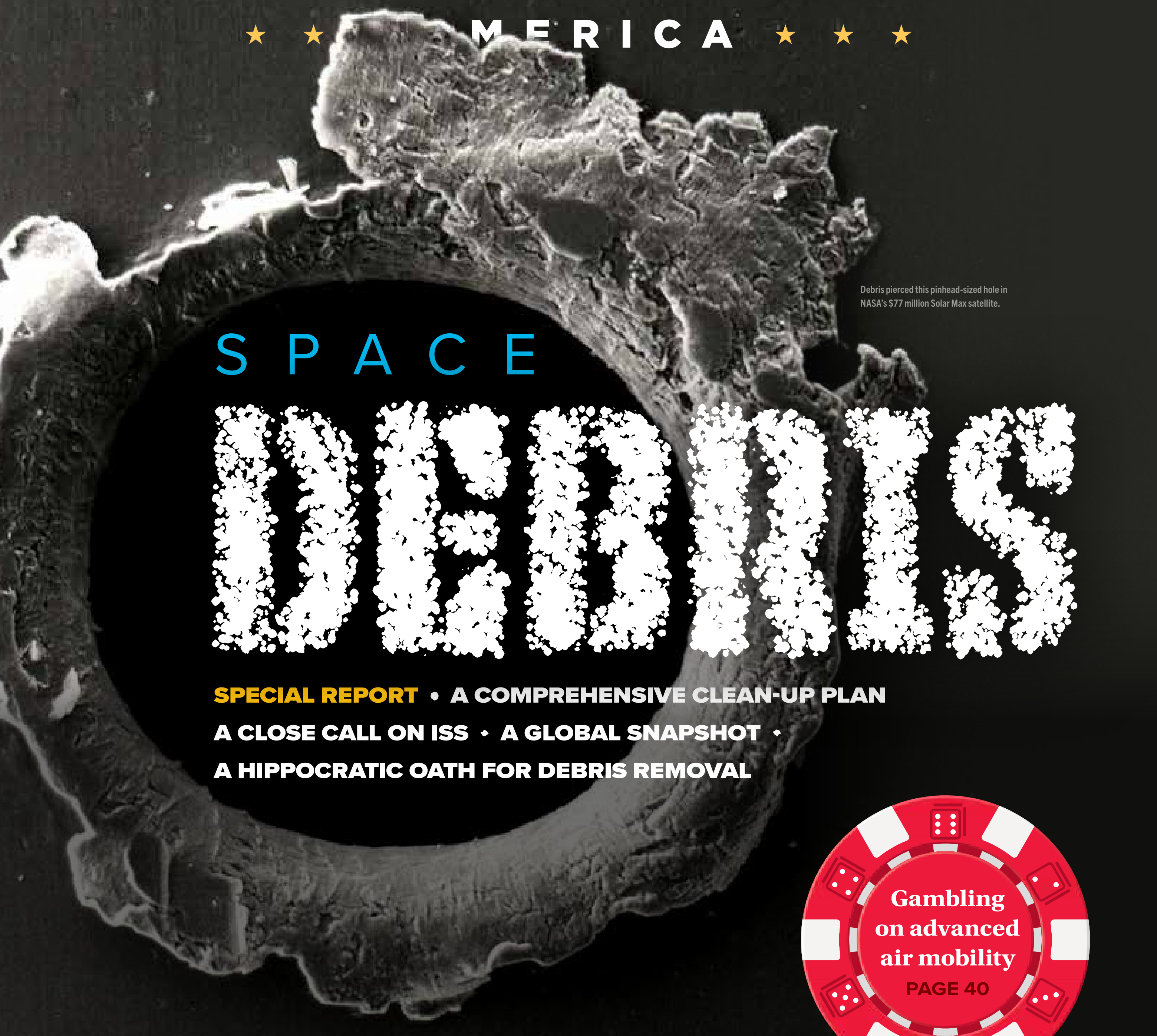

Debris pierced this pinhead-sized hole in NASA's $77 million Solar Max satellite.

SPACE DEBRIS

SPECIAL REPORT • A COMPREHENSIVE CLEAN-UP PLAN
A CLOSE CALL ON ISS • A GLOBAL SNAPSHOT •
A HIPPOCRATIC OATH FOR DEBRIS REMOVAL

Gambling on advanced air mobility
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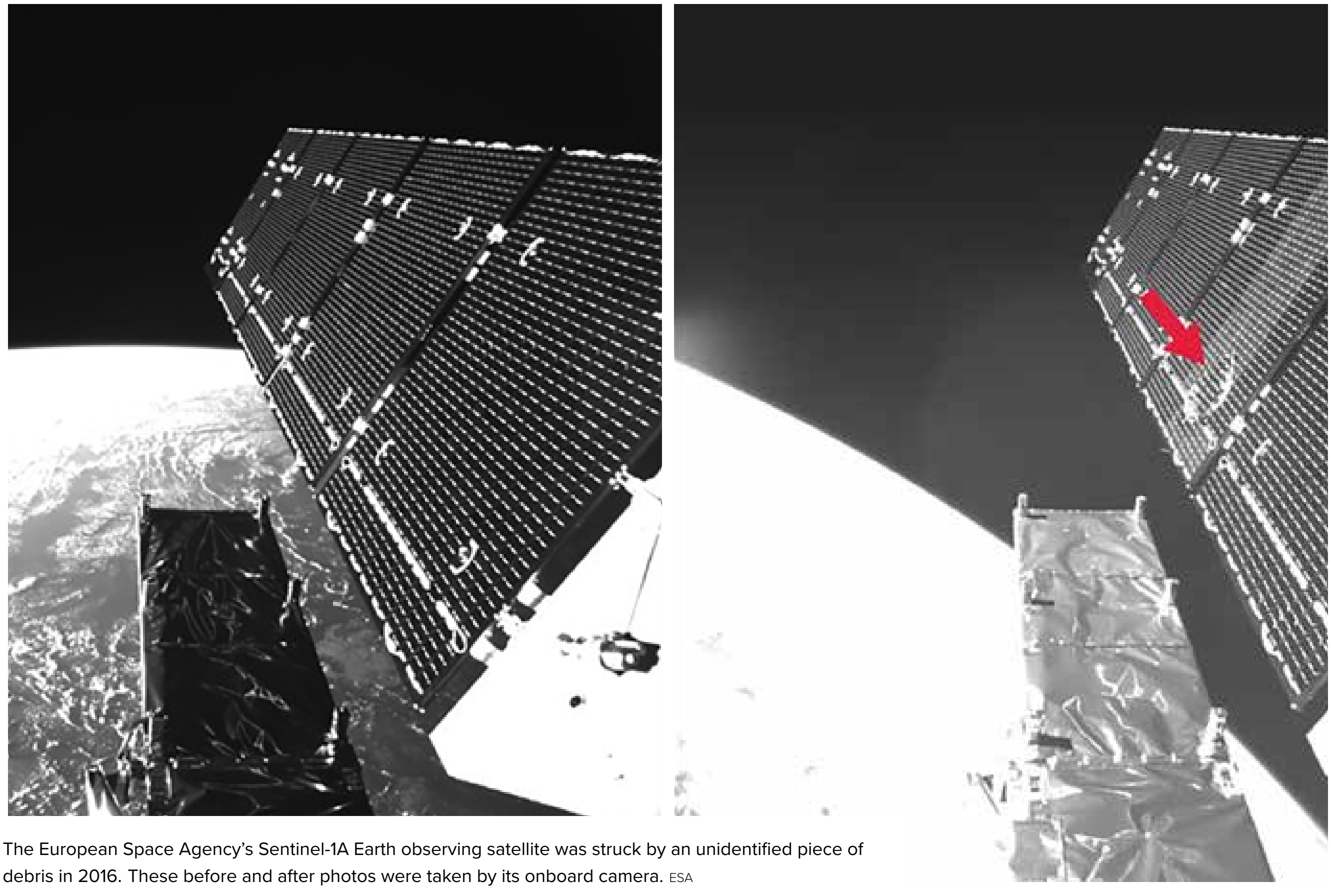

The European Space Agency's Sentinel-1A Earth observing satellite was struck by an unidentified piece of debris in 2016. These before and after photos were taken by its onboard camera. ESA

ON THE COVER: This 0.5-millimeter hole was among the dozens photographed in a flight control unit and electronics box of NASA's Solar Max satellite after space shuttle astronauts brought them back to Earth in 1984. NASA

AEROSPACE
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AIAA
SHAPING THE FUTURE OF AEROSPACE

IN THIS ISSUE

Keith Button

Keith has written for C4ISR Journal and Hedge Fund Alert, where he broke news of the 2007 Bear Stearns scandal that kicked off the global credit crisis.

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Moriba Jah

Moriba is an associate professor at the University of Texas at Austin and chief scientist at Privateer. He helped navigate spacecraft at NASA's Jet Propulsion Lab and researched space situational awareness issues at the U.S. Air Force Research Laboratory.

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Jonathan is a London-based space and science journalist who specializes in covering commercial spaceflight, space exploration and astrophysics. A regular contributor to Scientific American and New Scientist, his work as also appeared in Forbes, The New York Times and Wired.

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DEPARTMENTS

Lessons from DARPA's Gremlins and NASA's Space Launch System

I don't want to jinx things, but as I write this in late March, there is no burning issue in the news right now tied to our cover story about space debris. That said, the topic is always timely, and optimally, it won't take a calamity for spacefaring nations to at last stop creating space debris and figure out how to clean up the mess left so far.

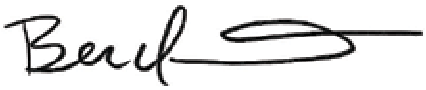
Turning to our story about DARPA's Gremlins program, the Dynetics concept for releasing drones from cargo aircraft and recovering them in midair brings to mind the war in Ukraine. Recovering and refueling drones safely away from the battlefield would be a tremendous advantage. As valuable a weapon as Ukraine's armed and camera-equipped Bayraktar TB2 drones have reportedly been, these aircraft look vulnerable with their advertised top speed of 220 kilometers per hour and their wheeled landing and takeoffs. Russian forces might not yet know how to knock the TB2s out of the sky or destroy them on the ground, but they could well figure it out. Ukraine only has perhaps 20 of them, according to media reports, and each one must be precious to troops and civilians. If the Gremlins technology were ready — and as our story indicates, it is not — some drones such as the TB2s could be operated directly by troops, but others could be released and recovered from the relative sanctuary of western Ukraine to provide intelligence and strike targets.

Let me switch topics entirely. The rollout of NASA's first Space Launch System rocket was goosebump-raising for many. Now that this program is getting on track, my hope is that NASA will reinvigorate research on advanced space launch propulsion. The agency abandoned much of that work in the 1990s, and it cancelled the X-33 reusable launch vehicle program without flying the vehicle and its linear aerospike engines.

Some research is going on toward revolutionary propulsion in the commercial sector, but the payoff from such technologies is so far in the future that companies, with their focus on near-term profits, might not be able to sustain the research and achieve the kind of rollout we saw with SLS.

Will SpaceX's Starship stack solve the problem when it launches to orbit perhaps in May? I doubt it. Reusing Starship's Super Heavy booster and the Starship passenger and cargo spacecraft atop would be a step in the right direction, but they're unlikely to make "space travel like air travel," which is the goal stated by Elon Musk. Super Heavy will be propelled by some 33 Raptor engines that will burn oxygen and methane. It will land upright to be readied for its next flight, but that many engines would seem to raise the odds of encountering significant maintenance issues between flights.

If the United States wants to help the commercial sector open the space frontier, NASA must serve as an R&D engine.★



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

Getting the public to care about space debris

I read Moriba Jah's column "Please Look Up" (February 2022) with great interest and would like to offer some wisdom from decades of experience viewing the public square. He is correct that people will only pay attention to a problem if they see it as harming them; they are too busy fighting the alligators next to their boat to be able to look at ones farther away.

Dr. Jah mentioned various ways to capture the public's attention. Appeals to altruism will sometimes work, but only when people can afford to be altruistic. Alarmism will only have a negative effect. The alarmist predictions of climate change activists over the last few decades are largely responsible for skepticism over current predictions. Saying "but this time I really mean it" does not restore credibility.

Dr. Jah is correct that it will take a cataclysmic event to wake people up to the problem of space debris, but his example of astronauts in the International Space Station having to take refuge hardly qualifies. The good news is that the cataclysmic event need not cost human lives: The 1994 collisions of pieces of Comet Shoemaker-Levy 9 into Jupiter, photographed by NASA's Galileo orbiter and other spacecraft, provided a wake-up call for society and led to the creation of NASA's planetary defense program.

Unfortunately, Dr. Jah misreads the message of Genesis. Humanity's original sin was trying to make ourselves into gods, not the denial of our connection to the rest of the universe. A better approach when appealing to Genesis would be to point out that God made us to be stewards of creation and that littering low-Earth orbit is bad stewardship.

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Let us hear from you

Send letters of no more than 250 words to letters@aerospaceamerica.org. Letters may be edited for length and clarity.

FLIGHT PATH

Recognizing and Overcoming Barriers to Participation in STEM

PreK-12 education in science, technology, engineering, and math (STEM) in the United States continues to face challenges at structural and academic levels. These challenges are exacerbated in socioeconomically disadvantaged communities. The consequence of below-par educational opportunities for students in these communities manifests in their underrepresentation in the STEM workforce. There is a correlation between socioeconomic status and race and ethnicity; and academic performance has been linked to socioeconomic conditions. Female, Black, and Hispanic students, and students with disabilities, also participate at lower rates than their white male peers.

Recognizing Barriers to Participation

Barriers to participation in STEM education – including socioeconomic, self-perception, physical, institutional, and societal constructs – significantly impact underrepresented or underserved communities, including individuals belonging to protected categories relating to race or ethnicity, gender, socioeconomic status, and disability.

Geographically speaking, the location of school districts indirectly impacts student access to STEM resources. Rural schools typically receive less funding than their urban or suburban counterparts. Educators in rural schools may "wear many hats," teaching many subjects concurrently, sometimes resulting in diluted STEM course content. In contrast, in urban or suburban districts, it's not uncommon to find teachers specializing in STEM subjects armed with cutting-edge tools and information.

School systems in lower socioeconomic status communities often are underfunded to meet the unique needs of the students. The schools are less likely to have enough resources to support student engagement in science when compared to more affluent areas in the same city or state. School systems that receive Title I funding often use the money for additional staff, intervention programs for remedial instructional support, and family engagement initiatives. These funds are rarely used to create high-quality extracurricular STEM programs, and if funding is allocated, the STEM programs occur outside of the school day, making it difficult for students to attend due to lack of transportation home, or working outside of school hours to help support the family.

A student's self-perception can create barriers to participating in STEM activities if they do not identify with the majority of participants. A student may react to implicit and explicit biases of other participants or program leaders. The lack of role models in the curriculum and program also directly impacts recruitment, engagement, and retention. If a student feels they are in a hostile environment, successful program engagement and retention are not possible.

Every child should have an equal opportunity to access the educational material they seek. Exclusion or mainstream education is widely accepted as a normative treatment in the modern educational system; however, it is not equitable. Students with disabilities find it difficult to participate in STEM programs largely because of the cost of inclusion. Many nonprofit organizations do not have the money to modify materials, equipment, and presentation of content. Additionally, expectations of people with disabilities can serve as a barrier to participation. STEM program leaders may not be knowledgeable about the implications or impact of a disability and therefore limit the student because they don't believe the student can understand the content or they do not know how to accommodate the needs of the student.

Addressing Barriers to Participation

AIAA is committed to improving access to STEM education for students. Providing access to quality STEM education programs is essential for the ongoing progress of our nation. These programs promote improved student academic performance and future opportunities. Employers benefit from having a more prepared workforce, which translates to a healthier economy.

There is no one-size-fits-all solution when discussing underrepresented students' barriers to participating in STEM activities. While the seemingly obvious solution may be to increase STEM program funding through grants and fundraising, funding is not the sole indicator of access. Instead, a multifaceted approach is needed to support students and facilitators.

AIAA supports helping STEM educators adapt to the 21st-century learning environment. This may include providing them with training on remote learning, as well as using the most current STEM education resources. Additionally, investing in and strengthening local programs will go a long way toward getting students interested in STEM careers. It is important to invest in educator training and resources in STEM so educators are best positioned to convey the material to students. Educators will need to use culturally responsive teaching principles to mold the educational content to best connect with their students' life experiences. Offering mentorship opportunities with community members who have pursued their own STEM career pathways will have many benefits, including helping inspire and excite students to pursue STEM careers, helping students reach beyond the classroom to apply STEM concepts, and sparking students' interest in STEM outside of school.

Robin Houston, Ethan Och, M. Javed Khan, Lorenzo Cabaero, Hali'a Bull, and Sharanabasaweshwara Asundi, ***AIAA K-12 Outreach Committee, Diversity Subcommittee***

The AIAA K-12 Outreach Committee, Diversity Subcommittee shares a common interest in promoting STEM and aerospace studies among students everywhere. Its members come from varied backgrounds and lived experiences that have impacted the way they approach Diversity, Equity, and Inclusion (DEI). The subcommittee invites AIAA members to continue this conversation on Engage at **engage.aiaa.org**. For more information on AIAA K-12 education programs, go to **aiaa.org/get-involved/k-12-students**. ★

"Seeing" dark energy

Q. Dark energy, of course, is invisible. Yet scientists discovered the existence of it partly through visible light observations from the Hubble Space Telescope. How can this be?

SEND A RESPONSE OF UP TO 250 WORDS that someone in any field could understand to aeropuzzler@aerospaceamerica.org by noon Eastern April 14 for a chance to have it published in the next issue.

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FROM THE MARCH ISSUE

WIND VERSUS SUNLIGHT

We asked you whether a solar sail could tack into sunlight similar to how a sailboat tacks into the wind. Your answers were reviewed by Bruce Betts, manager of The Planetary Society's LightSail 2 program, who helped us select the best answer.

WINNER "Tacking" a sailboat requires a resistive medium (the water) so that the wind load can be reacted on by lift generated by the hull moving in the water so that the resultant force has an upwind component. Space contains no resistive medium, so a solar sail cannot "tack." However, you do have one other force available: gravity. A solar sail in orbit around the sun can tilt its sail to face at an angle toward the direction of its orbit. The sunlight reflecting off the sail will produce a net force normal to the sail surface; this will be in a direction largely opposing its orbital velocity. This will reduce its velocity and hence kinetic energy, thus it will descend to a closer orbit of lower energy. In practice, with the very gentle continuous force of sunlight, it will have a spiral trajectory gradually getting closer to the sun.

Alan Sherwood, AIAA Senior member
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Sherwood is an aeronautical engineer at Boeing's Australia division, where he designs airframe structures for passenger and military aircraft.

AIAA AWARDS GALA

Celebrating Our Stars

27 April 2022 | 1800 hrs ET

Ronald Reagan Building and International Trade Center, Washington, DC

Join AIAA as we recognize individuals who have had tremendous achievements during their careers and continue to shape the aerospace industry. Our newly reimagined AIAA Awards Gala will take place under the stars outdoors at the Ronald Reagan Building and International Trade Center in Washington, DC. This setting will allow for free-flowing networking, social distancing and larger than life interactive exhibits.

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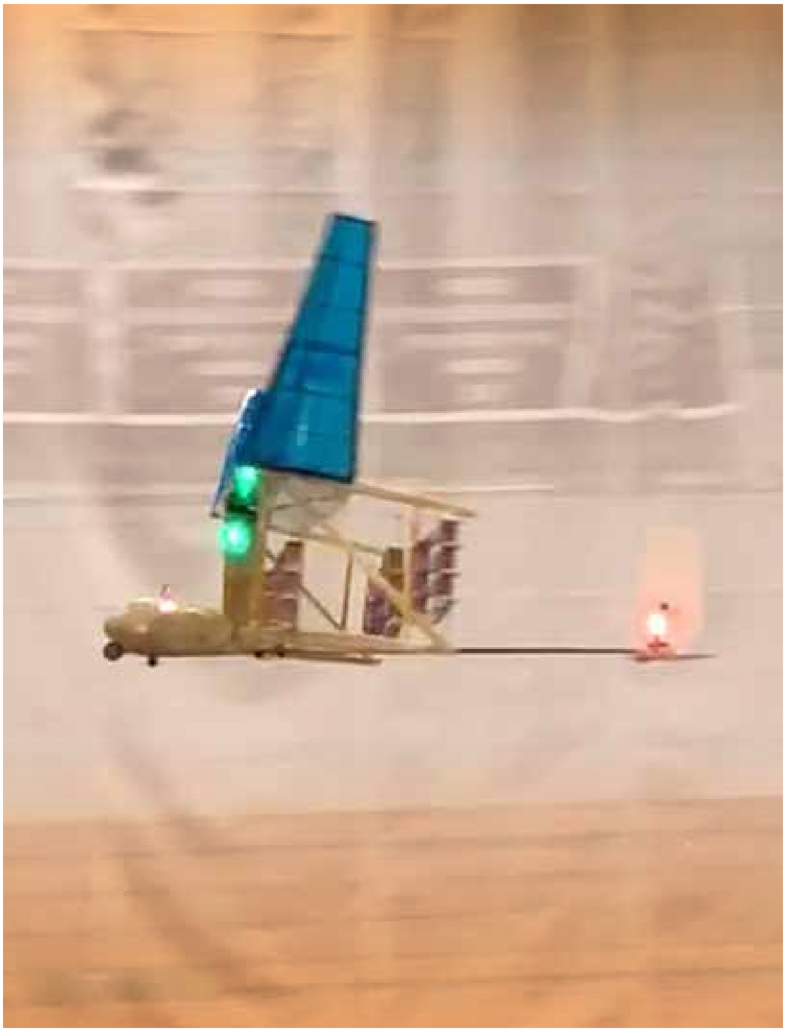
Vertical flight without rotors

BY AARON KARP
aaronkarp74@gmail.com



▲ MIT researchers flew a small, 2.2-kilogram prototype of their electroaerodynamic-powered plane 10 times in 2018. Once sprung from a bungee, the plane traveled 60 meters, the maximum distance possible within the gymnasium test site.

Steven Barrett/MIT

Steven Barrett of MIT has an idea that could disrupt the conventional thinking about what an electric vertical takeoff and landing aircraft should look like, and NASA has awarded him a $175,000 grant to explore the concept.

Four years ago, Barrett and members of his project team at MIT's Laboratory for Aviation and the Environment flew a small aircraft inside a gymnasium. Once sprung into the air by a bungee, the aircraft didn't need propellers or any moving parts to sustain powered flight. Instead, it relied on electroaerodynamic (EAD) thrust, achieved by feeding a charge through wires strung underneath the aircraft's wing to create an electric field that accelerates ions without the need for fuel.

Air taxi developers have generally settled on electric-powered rotorcraft as the only viable method of ferrying passengers in and between urban areas. Could the EAD technology be an alternative form of VTOL, the rotor-based vertical takeoff and landing designs that most air taxi business plans currently hinge on? To start the process of finding out, NASA in February awarded Barrett a nine-month, $175,000 grant to design a near-silent, nonrotorcraft VTOL and submit a report assessing the feasibility of applying the technology to "intra- and inter-city passenger transport," according to NASA.

That near-silence could turn out to be golden, given the desire to fly air taxis near residential areas at night without complaints. "It's likely that EAD will have its main application, at least in the foreseeable future, where noise is a critical concern," Barrett told me in an email exchange.

The primary technical barrier to be overcome is thrust density, Barrett said. A large battery producing 40,000 volts of electricity was needed to create enough power for the 2018 test flights.

"In other words, could enough thrust be produced in a small enough package to be useful? That's what we think we have a way of fixing in this project," he explained.

Barrett believes EAD-powered eVTOLs will eventually fly with passengers and cargo, but the initial application will be ferrying essential cargo, such as time-sensitive medical supplies in areas or at times when noise concerns would prohibit rotorcraft flight.

Any prototype or demonstrator eVTOL produced by MIT "will definitely be remotely piloted," he said, adding: "There's no real point nowadays to trying out risky technologies in any way other than a remotely piloted or autonomous vehicle."

When might such an aircraft fly? "It will likely take a few years to get to a good eVTOL demonstrator," Barrett added.

While this initial grant is for nine months, Barrett and MIT can apply for a larger follow-up grant that would cover an additional two years of study. ★

The last hurdle

AFTER A DECADE OF DEVELOPMENT, one final verification test is all that stands between NASA's first Space Launch System rocket, shown here shortly after sunset March 17 on its way to Launch Complex 39B at Cape Canaveral, and the design's first launch.

NASA late last year released a calendar of several possible launch windows for the Artemis I mission, an attempt to send an uncrewed Orion capsule slingshotting around the moon. But before committing to a launch date, NASA has said it wants to complete a fuel loading test and simulated countdown scheduled for early April. NASA watchers, nevertheless, are enjoying speculating over the likely launch date, and the consensus seems to be that between June 6 and June 16 is most likely.

The rocket made its 11-hour, overnight trek atop a massive crawler-transporter. In the wet dress rehearsal, NASA and its contractors will fill the dual tanks in the SLS core stage with liquid hydrogen and liquid oxygen while the launch countdown clock ticks down to just under 10 seconds. SLS then will be rolled back to the Vehicle Assembly Building to permit at least two weeks of analysis to verify that the rocket is ready for Artemis I. ★ — *Cat Hofacker*

PHOTO: JOHN TYLKO

NASA/Bill Ingalls

Climate communicator

Kate Calvin is the 11th chief scientist at NASA, but the first to juggle an additional mandate. She is also the agency's first permanent senior climate adviser. In that role, she must carry out the Biden administration's pivot to prioritizing the study of Earth's changing climate and the search for ways to lessen its impacts of that warming. That involves elevating the profile of NASA's Earth-observing satellite programs, some of which the Trump administration attempted to stop funding. She also strategizes with NASA's communications office about how to share this data with the general public. Here's our conversation, condensed and lightly edited. — *Cat Hofacker*

KATE CALVIN

Positions: Since January, chief scientist and senior climate adviser at NASA; Earth scientist at the Pacific Northwest National Laboratory's Joint Global Change Research Institute in Maryland, 2008-2022, where she modeled various climate scenarios, such as how forests would change as the Earth warms.

Notable: NASA's first chief scientist to double as the agency's senior climate adviser, a position created to ensure NASA helps carry out the Biden administration's climate objectives. At the Pacific Northwest National Lab, she created Representative Concentration Pathways, a common set of scenarios that scientists studying different aspects of climate change can use to simulate how changes, such as changes in emissions and land cover, might affect the entire planet.

Age: Declined to say

Resides: Washington, D.C.

Education: Bachelor of Science in mathematics and computer science, University of Maryland, 2003; Master of Science in 2005 and Ph.D. in 2008, both in management science and engineering, Stanford University.

Q: How does combining the roles of chief scientist and senior climate adviser reflect how NASA is prioritizing climate research?

A: The reason that we've combined the roles is to lead with climate science, and the roles are very similar in the sense of the kinds of activities that are going on. So as senior climate adviser, I'm connecting climate across the agency. We have research and technology development at different centers at different parts of the organization, and I'm trying to connect that and amplify that and work with interagency partners and international partners to coordinate on those efforts and make sure that they know what NASA is doing. We can also help facilitate their use of NASA information. As chief scientist, I'm doing those same sorts of tasks but with the broader science portfolio — trying to connect it across the agency and communicate that externally and work with other agencies and international partners on things related to science more generally. We work with some of the same agencies on broader science and then also on Earth science, so sometimes it's just about talking to a different part of different agencies.

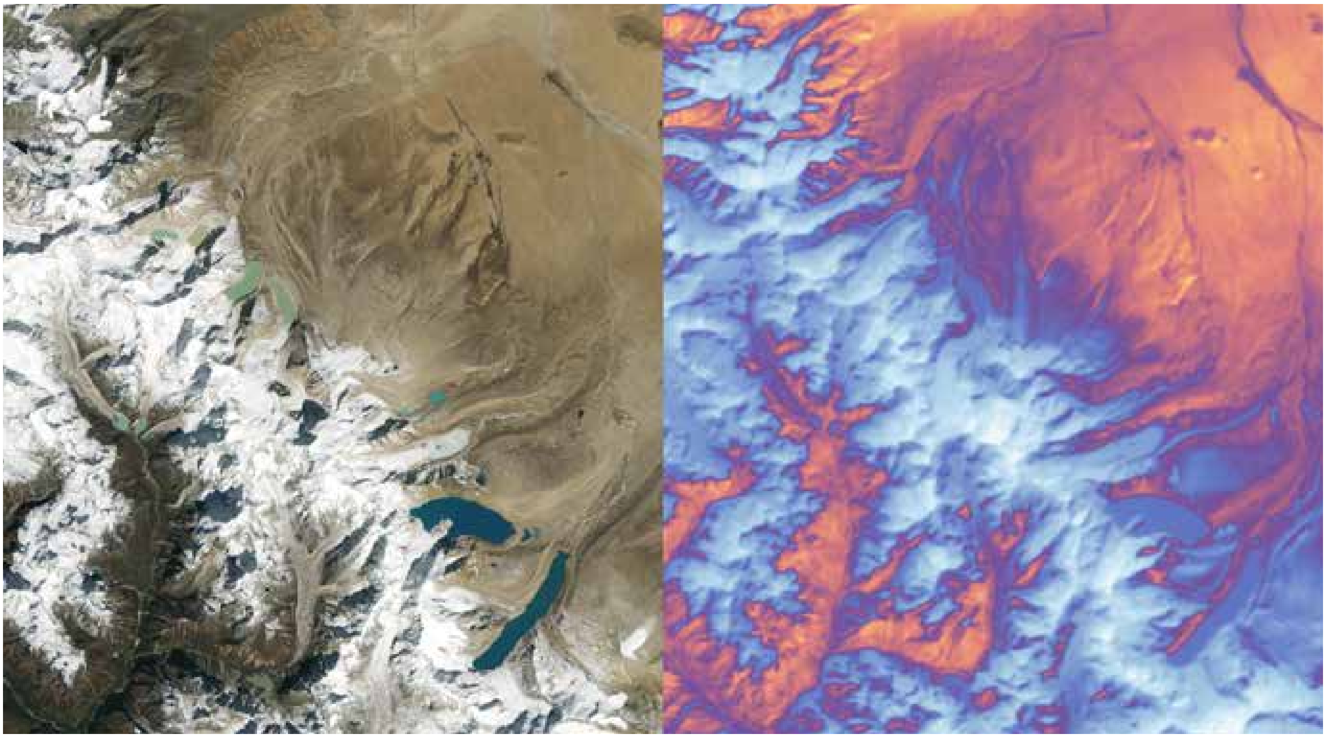
Q: In terms of the strategy for emphasizing climate research, how much is it about starting new programs versus connecting existing programs back to the topic?

A: On Earth observations, we have decades of data that we've collected about vegetation, temperature, precipitation, clouds, carbon dioxide. And because we've been observing this for a long time, we can see both the state of the Earth today and also how it's changed. We use this information in our models to help us understand drivers of change and also where we might go in the future. We have applied science programs that work with different stakeholders to provide Earth observing and other applied science information that can help support local responses. So before, during and after disasters occur, we can provide information on the ground to help support that. We can look at where wildfires are burning, emissions and air quality associated with fires. We can look at burn perimeters and burn scars. We are also developing technologies that help mitigate or adapt to climate. Our aeronautics team has been working for a while with the aviation industry to help reduce fuel use and emissions. Then in our space operations directorate, we know that living in space and operating in space present challenges that could have applications on Earth. We grow crops in the International Space Station, and some of the things that you develop to grow a crop in space have benefits on Earth. NASA scientists have worked to develop LED lighting that's now used in indoor agriculture facilities. There's a lot of work like that going on, and part of my job is trying to connect that and communicate that.

Q: What are some of the space technologies you're interested in finding Earth applications for?

A: The water processing system on the International Space Station. Some of the technologies used for that water processing have been used on Earth to help provide clean water in places where it's harder to get. NASA scientists have also worked on formulating fertilizers that reduce runoff. They try to get nutrients to the plant roots at the rate they need it, and that reduces runoff, which has implications for water quality on Earth. We've also made fertilizers that are more precise, so more nutrients are absorbed by the plants, and less are going into rivers and streams. We've developed sensor technologies to sense things in outer space that could also be used to observe Earth. For example, the sensors used in the James Webb Space Telescope informed the development of sensors used in the Orbiting Carbon Observatory missions, which measure carbon dioxide on Earth.

"The more information we provide about Earth and the more we can help people use it, the more informed decisions they can make."



▲ These photos of the Himalayan mountains were taken by two different cameras on the Landsat 9 satellite in different wavelengths for purposes including measuring surface temperatures. In the photo at right, taken by the satellite's Thermal Infrared Sensor 2, the blue-white color indicates the cooler temperatures of the glacier and lakes, and the orange-red shows the relatively warmer temperatures of the Tibetan Plateau.

NASA/USGS

Q: What you're describing sounds like a way for NASA to advance technologies related to climate change without sacrificing its diverse range of programs.

A: It's important that we still explore space. We can learn a lot about Earth by observing other planets. Venus is thought to have been habitable once, but it's now very, very hot. Some of the research on the greenhouse effect on Venus and ozone on Venus has informed what we know about the greenhouse effect and ozone depletion on Earth. Similarly, our several rovers and the helicopter exploring Mars will hopefully help us understand better the climate changes that Mars has undergone and how they apply to Earth as well.

Q: On Earth observations, some of those satellites have been operating for decades now. As NASA looks at upgrading the fleet, what technologies are you excited about?

A: There are programs where we continue to collect the same sort of data, just better and better over time. We just in September launched Landsat 9, and we're coming up on a 50-year record of Landsat. I just saw a display of results from Landsat earlier this week. They showed land use in the same space from the beginning of the Landsat record to today so you can observe the land use and land cover change — which is what Landsat is designed to study — and changes in vegetation. But you also see the improvements in these satellites. You get finer and finer resolution and better-quality data over time. We are also designing a new Earth System Observatory, a set of satellites that are designed to work together to provide a 3D holistic view of the earth. The first one, NISAR [NASA-Indian Space Research Organization synthetic aperture radar] will look at changes in the Earth's surface in a way that'll help us understand changes in ice sheets and ice sheet collapse and changes in landslide and other surface dynamics. The more we understand about the planet and how it's changing, the more we can give people information that they can use to respond to it. So we're continually trying to expand the observations. We get that data out to people who can use it, and we provide support and training on data. We're trying to continually make it more accessible — not just the data but also the science. We work with local stakeholders and decision-makers through our disasters program area in the Earth Science Applied Sciences Program to help

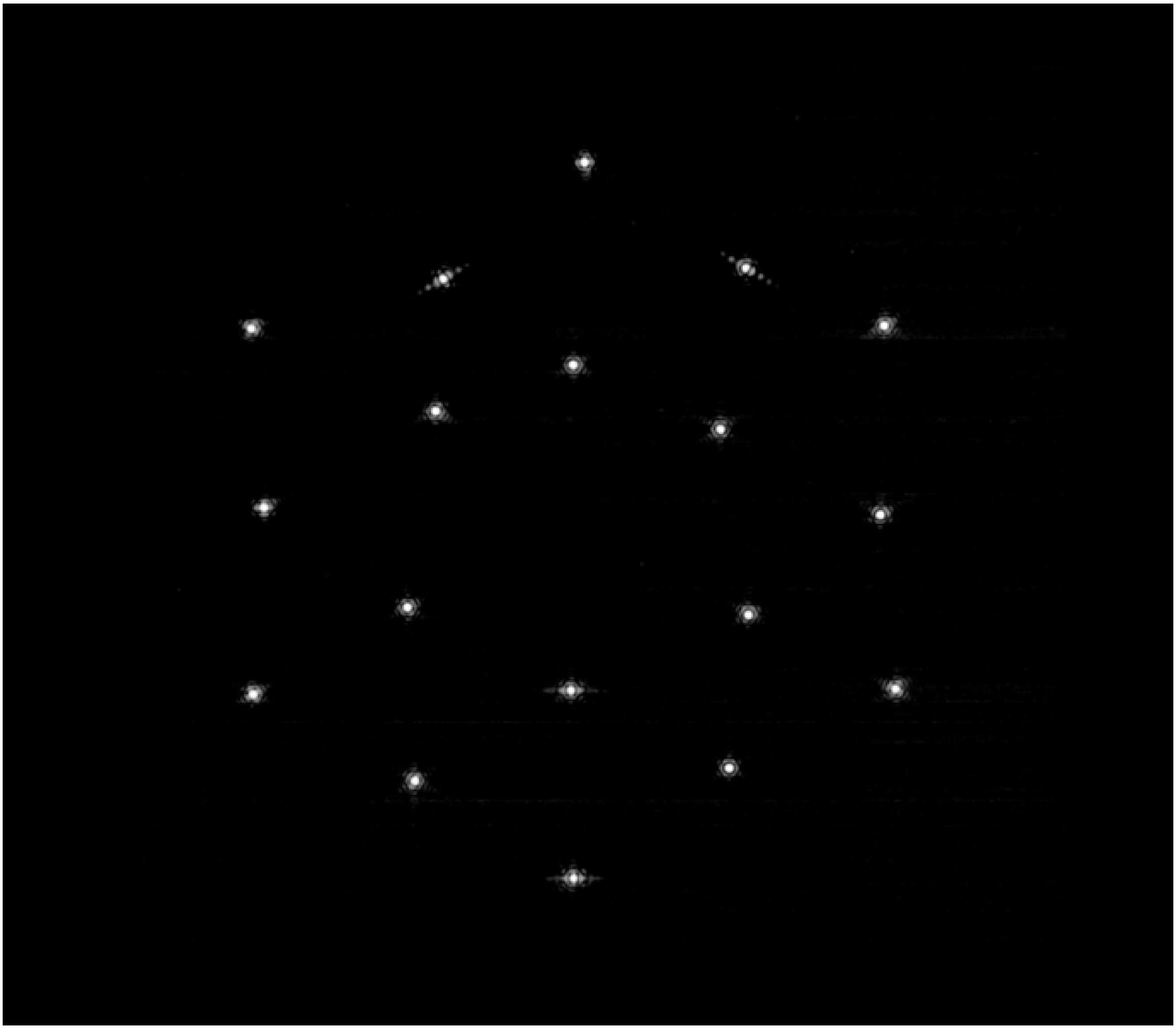
support this. For instance, with the VIIRS [Visible Infrared Imaging Radiometer Suite] instrument on one of our polar-orbiting satellites we can look at power outages: You can see the lights at night, and that gives you a sense of where you have power outages from a storm. You can use other instruments to look at changes in the land surface from tornado tracks or burn scars. And you can put all that together. The more information we provide about Earth and the more we can help people use it, the more informed decisions they can make.

Q: What's still missing in your climate modeling?

A: There are questions around clouds and climate change and trying to get at how much will the Earth warm for a given level of emissions. One of the satellite missions that is coming up later this year is called SWOT [Surface Water and Ocean Topography], and it's going to look at surface water and oceans. It'll give us the first complete survey of water running through rivers and lakes. In my old research, we were looking at how water scarcity might change over time. In order to get at that, you have to know how much water people need for energy or agriculture or other activities but also how much water is available. And we don't really have a complete sense of that right now, much less how that'll change in the future. So something like SWOT is really important for understanding that and better constraining models and giving us a sense of how that might unfold in the future. SWOT's also going to look at oceans, which play a really, really important role in climate change because they absorb heat and carbon. How the ocean mixes and circulates affects how much more carbon it can uptake and how much more heat, which has implications for future climate change.

▲ Technicians at NASA's Jet Propulsion Lab began assembling the science payload for the Surface Water and Ocean Topography (SWOT) satellite in January. The satellite, developed jointly by NASA and the French and Canadian space agencies, is scheduled to launch in November to conduct the first global survey of surface water content.

NASA/JPL-Caltech



Q: You mentioned how the Landsat data has gotten more refined. How do you ensure data continuity so scientists are still able to compare the new datasets with measurements taken decades ago?

A: This is something that scientists have been dealing with for a while. So when you look at something like temperature records, we have information from surface stations that go back years. Before that, we have information from tree rings and ice cores. Scientists spend a lot of time thinking about how we can make this all work together to make a more complete picture so that you have a longer time series of information. Exactly how you do that depends on the data that you have and what you're working with. One part is just being really clear about what you're showing. Are you looking at surface temperature, meaning the actual temperature of the Earth itself, or are you looking at temperature 2 meters above the surface? That's something we're communicating more publicly; often to the public we just say temperature, but among the scientific community, it's really important to be precise about exactly what you're measuring. Then when you use a model, you want to run it over historical periods so you can see how it compares. You can use information from satellites to better understand your model and to constrain your model.

Q: You touched on public perception of climate change, which hasn't shifted much in the past five years, according to a Gallup poll done in early March. How do you respond to skeptics?

A: NASA enjoys a broad public trust and support for science. Our science shows that climate is changing. We're seeing warmer temperatures. There are more extreme events that come along with that, so we've seen more heat waves and extreme precipitation

▲ Calvin says NASA's frequent updates about the James Webb Space Telescope's commissioning is an example of the agency's committment to transparency. This photo taken by Webb's Near Infrared Camera is one of several images the agency has released.

NASA

"Part of building trust and communication is being transparent and open, and this is why NASA is really pushing on open data and open science. All of our satellite and observation information is already readily available to the public, but we're working on making it easier to use and showing not just the data but how we got there."

events and wildfires associated with that. We communicate that to the public broadly. We have lots of different avenues to get information out: social media, news releases, materials for children. Part of building trust and communication is being transparent and open, and this is why NASA is really pushing on open data and open science. All of our satellite and observation information is already readily available to the public, but we're working on making it easier to use and showing not just the data but how we got there. One of the things that I really appreciated watching the last couple months is the news releases and web posts about the James Webb Space Telescope. We've been showing along the way what's happening, what it takes to get a telescope like that out to its orbit and producing science images. That's really important in communication: to show what's happening and be very transparent about the whole process, not just the end result.

Q: Looking across NASA, what's a big topic or trend that is going to shape the science goals in the coming years?

A: I would say two things. One is we do have a lot of really exciting Earth science missions coming up. I mentioned SWOT that will help us understand rivers and ocean. We have NISAR that's going to help us understand changes in air surface, like landslide and ice sheets. We also have TROPICS [Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats], a set of six satellites that will measure temperature, humidity and precipitation in the tropics. The EMIT [Earth Surface Mineral Dust Source Investigation] instrument will be put on the exterior of ISS to help understand mineral dust, which has implications for local climate and air quality. Second, the Artemis program is starting. I'm really excited about the human and robotic efforts to explore the lunar surface. I'm excited to watch the Artemis I mission this year. ★

CATCHING A "GREML

IN”

Military drones are alluring tools for spying and striking targets, but getting them flying where they need to be is a challenge. What if conventionally piloted cargo planes could fly to the outskirts of a battlefield, release a swarm of such drones, and then recover them for refueling and reloading? Keith Button tells us how DARPA and Dynetics brought this vision to the edge of reality.

BY KEITH BUTTON | buttonkeith@gmail.com

Last year, in a control room at Dugway Proving Ground in Utah, engineers intently watched a video screen showing the view from a Mini Cooper-sized drone flying over the nearby desert. The drone had been released from the wing of a C-130A cargo plane about an hour earlier, and now they could see the drone slowly approach a bullet-shaped fixture dragged by a cable from the same plane. The group let out a muffled cheer as the drone attached itself to the fixture and began to ascend on a winch. A full-throated cheer erupted moments later when the drone reached the plane and was recovered.

Why so much excitement? Because this October day was the last day in the test program, and Dynetics, the Alabama company whose concept DARPA chose in 2018 for flight testing, had yet to capture and retrieve one of its drones, which weigh up to 680 kilograms. The successful capture vividly demonstrated the potential for dispatching swarms of drones to fly over a battlefield to be recovered later in midair.

Creating the concept

Dynetics knew that the safety of the C-130A crew was the top priority. The plane would have a crew of 14 aboard, larger than normal because of testing. The drone and C-130A would each be flying at about 270 kilometers per hour, with the C-130A leaving a turbulent wake. Flying the drone straight into the cargo hold was obviously out of the question.

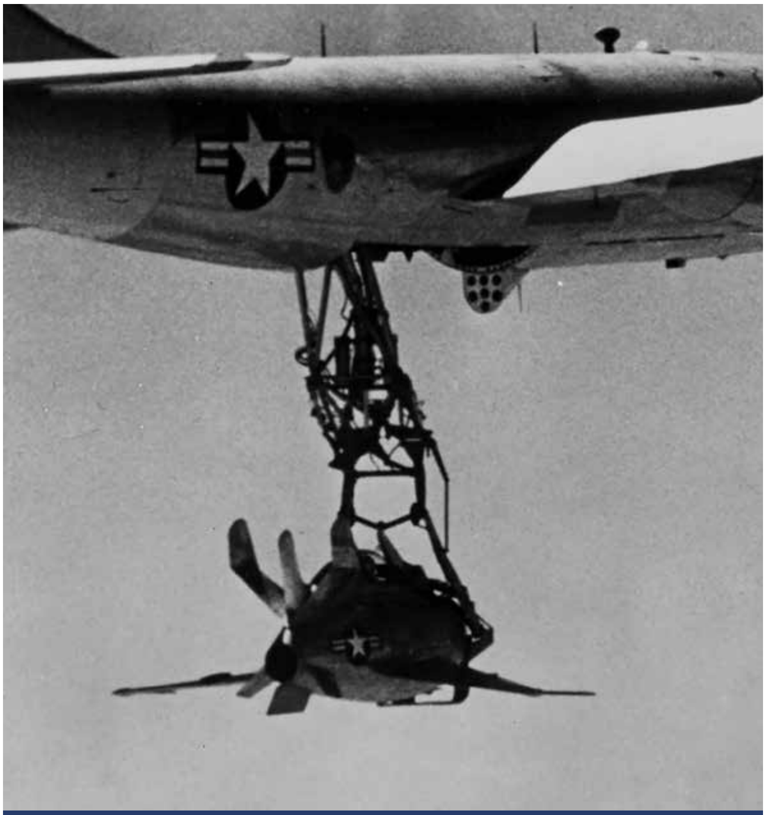
"That would be difficult to do because of the flow fields behind the larger aircraft, and very unsafe of course," says U.S. Air Force Lt. Col. Paul Calhoun, DARPA's Gremlins program manager and a former C-17 pilot.

Dynetics decided to capture the drone at a distance of 9 to 15 meters behind the C-130A on a cable and have the drone fold in its wing and shut off its turbojet engine to avoid any chance of it flying out of control.

A big question was how to grab the drone midflight. Inspiration came from the shuttlecock-shaped drogues at the end of aerial refueling hoses, says Tim Keeter, the Dynetics program manager. In refueling, a probe on the receiving aircraft fits into the wide end of the shuttlecock. Dynetics created a version of this concept centered on a bullet-shaped device that would be attached to the end of the cable. Stability would be a challenge, so Dynetics added four grid-shaped movable fins that would automatically adjust to prevent any fluttering motion from developing as a Gremlin approaches the bullet to dock. The Gremlin would then sprout a short docking arm from the top of its fuselage at about its midpoint and fly forward to insert this arm into the bullet fixture. Mechanical clamps inside the bullet latch onto the arm to secure the Gremlin, initiating the wing folding and shutting down the drone's engine.

A Dynetics Gremlin drone approaches "the bullet" capture mechanism in October ahead of the design's one and only successful capture. The vehicle was one of three surviving in the test program. Two others crashed, one in January 2020 and one in October.

DARPA/Dynetics



National Museum of the United States Air Force

Drawing on history

The name "Gremlins" is a play on the U.S. Army Air Forces' Goblins concept of the 1940s in which a long-range bomber was to carry a conventionally piloted Goblin jet inside it. The Goblin would be released for protection then retrieved via trapeze. This way, a fighter escort would not have to fly for hundreds of kilometers. Two Goblin XF-85 test aircraft were ordered from McDonnell in 1945, and tests were conducted with a B-29. Frustratingly, "about half of the Goblin flights ended in emergency landings after the test pilot could not hook up to the B-29," according to the National Museum of the United States Air Force. Goblin and other variations of the larger-planes-carrying-smaller-ones concept were scrapped, mainly for safety reasons: Pilots were killed or were forced to crash land after collisions during test flights. That history of danger influenced the Gremlins program priorities. — *Keith Button*

To keep the Gremlin from flopping around, the docking occurs above the combined center of gravity of the drone and 90-kilogram bullet. The Gremlin also has fins for stability. With its engine now shut off, the fins are powered by battery.

A winch on the C-130A slowly reels up the Gremlin to minimize any pendulum motion. The drone's fins also adjust to damp any pendulum tendencies. For the final step of the retrieval, a mechanical arm hangs out the C-130A's open rear door about 2.5 meters below the plane to embrace the drone and pull it through the worst part of the wake turbulence and into the plane.

Retrieving the drones through hands-on remote control would be impractical because of the communications latency and the required precision and minute adjustments. So Dynetics needed to craft autonomous flight software. The company turned to its subcontractor, Sierra Nevada Corp., which had written control software for the 2006 DARPA Autonomous Airborne Refueling Demonstration Program in which an F/A-18 autonomously connected to a refueling drogue trailing from a B-707 tanker.

"That was attractive to us as a good starting point for what Gremlins was going to have to deal with,"

▲ A Gremlin drone approaches a C-130A cargo aircraft over the desert near Dugway Proving Ground in Utah. The recovery of this particular Gremlin was the culmination of nearly two years of test flights.

DARPA/Dynetics

Keeter says — autonomously flying the drone to its intended target, the bullet, accurate to within few centimeters, with the ability to track and lock on to the bullet target for docking.

While the design ensured that a capture would occur below the C-130A's wake, air flow still presented challenges. As the distance between the bullet and a Gremlin closes, the air flowing around each of them interacts and sets up a periodic up-and-down motion in the bullet that the software must predict or the docking will be missed. Indeed, until the October flight the drone kept missing, because the bullet would move away from the point the software was aiming for.

"If you're always trying to chase to where it used to be, because there's some lag in any control system, you never quite get there. So we have to predict where we're moving to," Calhoun says. So the engineers improved the tracking algorithm to better predict the periodic motion of the bullet and to aim for where it would be a split second in the future.

Another goal was to make sure that just about any cargo plane could be equipped to retrieve Gremlins or, if necessary, take control of them from the autonomous control software. So Dynetics designed the retrieval and control equipment to be installed on two standard cargo pallets that could be rolled on and off the plane. In the flight tests, the larger of the two pallets held the retrieval equipment, and the smaller one carried a two-seated control station from which managers permitted the autonomous retrieval to proceed to the next step.

Looking ahead

Whomever takes over the next stage of Gremlins development will want to improve the technology so the capture is more accurate and automatic, Calhoun says. That way, multiple drones could be recovered quickly, which is the ultimate goal.

"It's probably not completely solved. I think that we all believe that we can do even better," he says.

Another next step will be capturing the drones at higher velocities, which would mean designing the Gremlins to fly faster also. The C-130A model like the one flown for the Gremlins program is an early design that opens its rear door while flying up to 278 kph. The modern C-130s and other cargo planes flown by the U.S. Air Force can open their doors while flying up to 463 kph, so they could retrieve faster drones. ★

29 A close call on ISS

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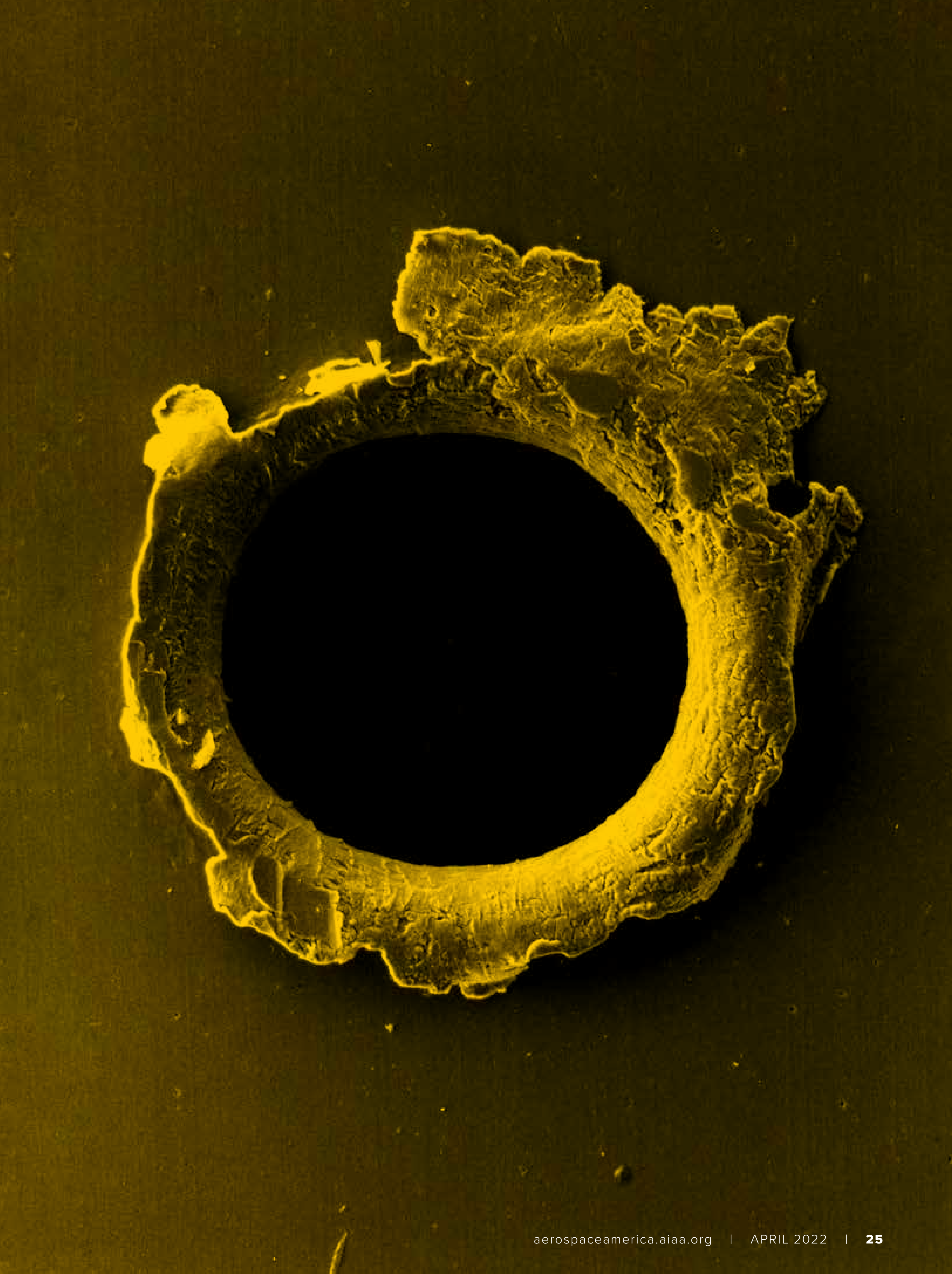
34 A Hippocratic oath for debris removal

HOPE FOR SOLVING SPACE DEBRIS

After decades of spaceflight, Earth orbit resembles the Wild West mixed with a demolition derby. Traditions rather than laws govern behaviors, and every now and then a frightening crash litters the track. Our modern lives, the safety of astronauts, space adventurers and the security of the free world depend heavily on this poorly managed domain. Can a brighter future be forged? Jonathan O'Callaghan found reasons for hope.

BY JONATHAN O'CALLAGHAN | jonathan.d.ocallaghan@gmail.com



SPACE SPECIAL REPORT DEBRIS

Celine D'Orgeville has a space laser. More specifically, her team at the Australian National University has built a laser that could nudge pieces of space junk off collision courses. As far as she can tell, the laser is the only one like it on the planet.

The project has stalled, however. D'Orgeville and her team ran out of funding before they could test the laser at Mount Stromlo Observatory in the hills of Canberra in Australia. As such, the world's only known space junk laser is currently disassembled and sitting in storage. "I wish we could demonstrate this technology," says D'Orgeville. "That's the frustration that comes with research."

Nevertheless, the laser exemplifies the industry's growing determination to solve the space junk problem, the rich tableau of ideas about how to do it and the fact that it won't be easy.

Today, some 5,000 active satellites orbit our planet, along with 2,500 dead satellites and tens of thousands of articles of debris bigger than a baseball. If one counts objects down to the size of a popcorn kernel, the total grows to millions, thousands from widely derided anti-satellite tests conducted in recent years by China and Russia. Any one of these pieces of debris could, depending on the impact location, destroy a satellite or poke a hole in a crew capsule or habitat and cause a potentially deadly depressurization.

"It's only a matter of time before human lives are lost because of a piece of garbage," says Moriba Jah, a space environmentalist at the University of Texas at Austin and an Aerospace America columnist.

If nothing is done, the amount of junk is certain to grow as satellite numbers continue to rapidly increase. In the past two years alone they have nearly doubled, and by 2030, an estimated 150,000 active satellites could be in space, due in part to the megaconstellations being launched by companies including SpaceX in the United States and OneWeb in the United Kingdom.

▲ Debris pierced a small hole in one of the segments of the robotic Canadarm2 on the International Space Station in 2021. NASA flight controllers and ground specialists in Houston discovered the damage in May while inspecting the arm with cameras mounted to the exterior of ISS.

NASA/Canadian Space Agency

In the worst-case scenario, one collision could trigger a series of cascading collisions among pieces of junk and operational satellites that would spread orbital pollution widely and dangerously. This worry was modeled in 1978 by meteoroid scientist Donald Kessler of NASA's Johnson Space Center in Houston, who retired in 1996. The Kessler Syndrome, as the scenario was eventually dubbed, could make it impossible to launch satellites or humans to certain orbits because the risks of collisions would be too high.

Some argue the syndrome has already begun.

"It's just happening on time scales of decades and centuries, like climate change," says Brian Weeden, director of program planning for the Secure World Foundation of Washington, D.C.

Can the trend be stopped or even reversed?

"We're starting to see a deeper understanding of what's required," says Hugh Lewis, a space debris expert at the University of Southampton.

For Jah, his epiphany came in 2006 when he moved to the Hawaiian island of Maui and saw the effect of tourism and the garbage it produced on the otherwise idyllic locale. Observing space with a telescope from the island's highest mountain, he saw the same thing taking place in space.

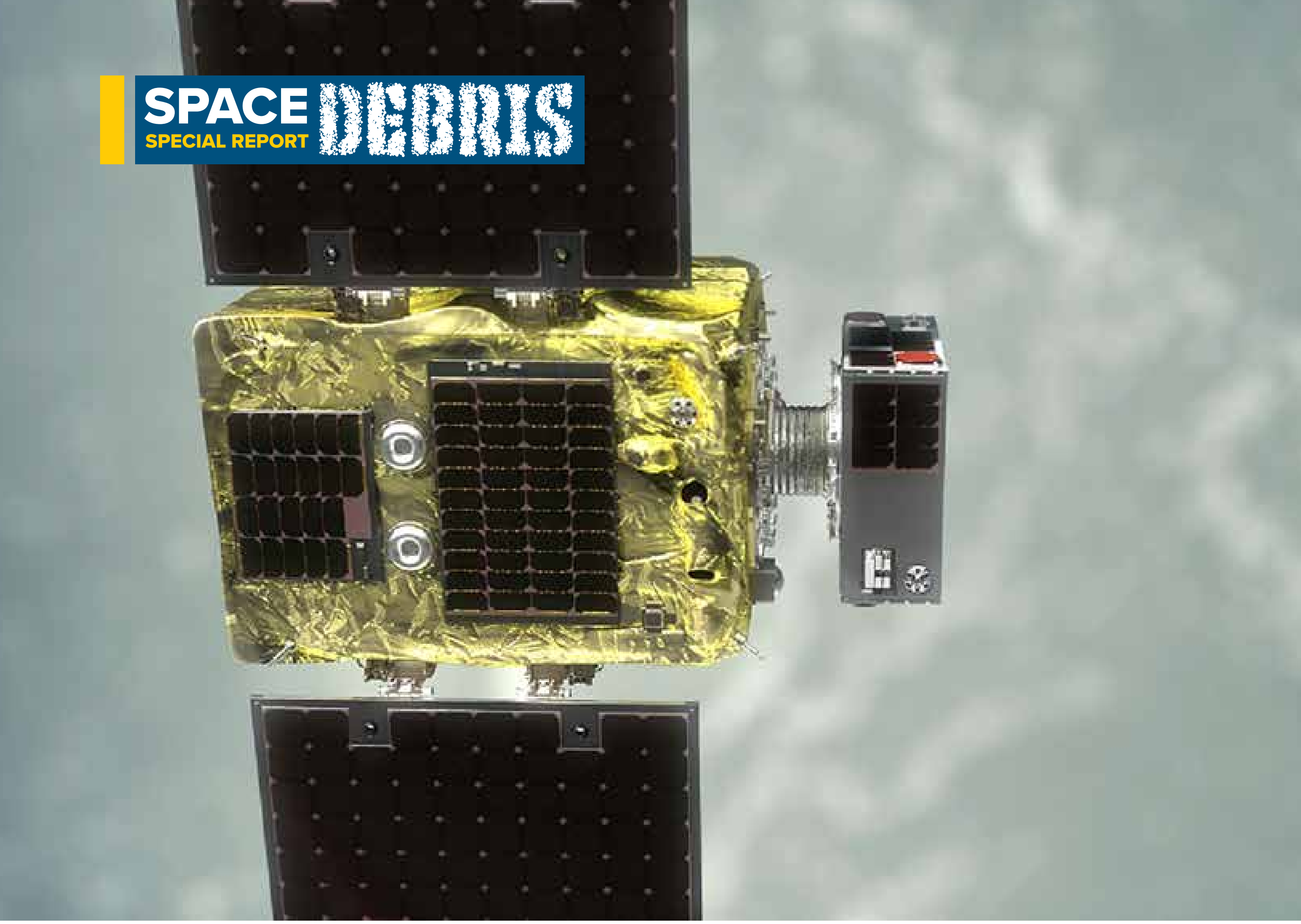
"Most of the objects up there were garbage," he says. "It really upset me."

Jah and others set about raising the profile of the issue. Today, experts in the field see three interrelated goals that together offer the best chance of solving the space junk problem:

- Objects must be prevented from colliding.
- The most dangerous debris, such as dead satellites and derelict rocket stages, must be removed.
- Rules must be established to prevent the creation of new debris, perhaps including a bar on anti-satellite weapon tests.

Preventing collisions

Preventing collisions requires careful tracking and, if necessary, a maneuver to avoid an impact. Traditionally, satellite operators in the United States



have relied on data and alerts from the U.S. Air Force and later Space Force to know when it's time to maneuver out of the way of debris or other satellites. The projections have been less than perfect though. In 2009, the risk of collision was not properly realized in advance of one of the most infamous space junk incidents. The active Iridium 33 communications satellite and the defunct Russian communications satellite, Cosmos 2251, collided over Siberia, shattering them into nearly 2,000 new pieces of debris, much of which still orbits Earth today.

To prevent this from happening again, more rapid and accurate tracking of satellites and debris in orbit is needed. One company leading this field is LeoLabs of California, which currently operates four radar sites in Alaska, Costa Rica, New Zealand and Texas, and plans to open more in the coming years.

"With the four radar sites, we cover all orbits," says Daniel Ceperley, the company's CEO and co-founder. "Now we're in the process of building up more sites so we get more timely information," he says, referring to the company's plan to ultimately operate at least 20 radar stations.

Whereas legacy databases such as the Space Force's update positional information on satellites every eight hours, LeoLabs can do so within minutes.

"Eight hours is not sufficient warning time" if a close pass of two objects, called a conjunction, might be in the cards, says Darren McKnight, the company's senior technical fellow. "Any object that crosses one of our radars, within seven minutes we reissue conjunction data messages to all of our customers."

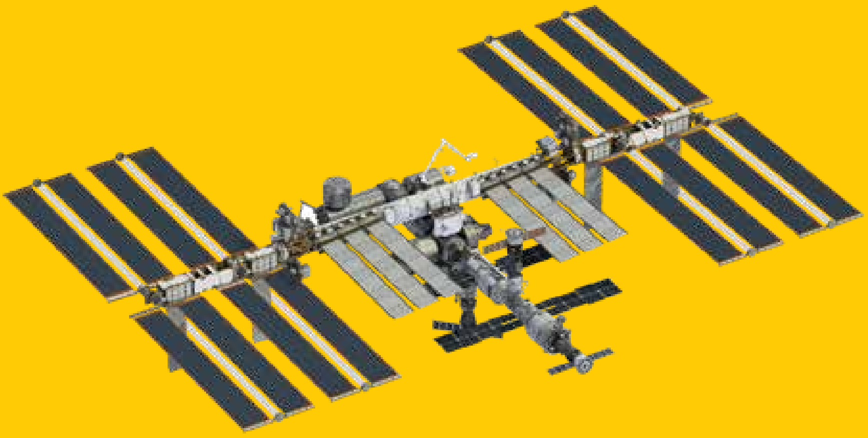
About 60% of satellite operators in low-Earth orbit — including OneWeb — currently pay for access to LeoLabs' alert system. In a typical year the company says it will identify about 800,000 possible conjunction events, and that number is only set to grow as more satellites are launched.

Other companies are looking at different approaches to the problem of space traffic management. Privateer of Hawaii emerged from stealth mode in March to say it will launch sensor technology to space that can track debris as small as a few centimeters, a similar size to LeoLabs. Apple co-founder Steve Wozniak and robotics entrepreneur Alex Fielding founded the company with Jah.

"Our life on Earth is connected to space, and even the smallest debris orbiting the Earth can damage and destroy these critical capabilities," Wozniak said in an emailed statement through a spokesperson. "My

▲ In this rendering, Astroscale' s servicer satellite (left) is magnetically joined to the client satellite by a metal plate (center). The servicer and client have made several autonomous close-range captures and releases over the past year in preparation for more difficult captures at longer distances.

Astroscale



SPACE STATION CLOSE CALL

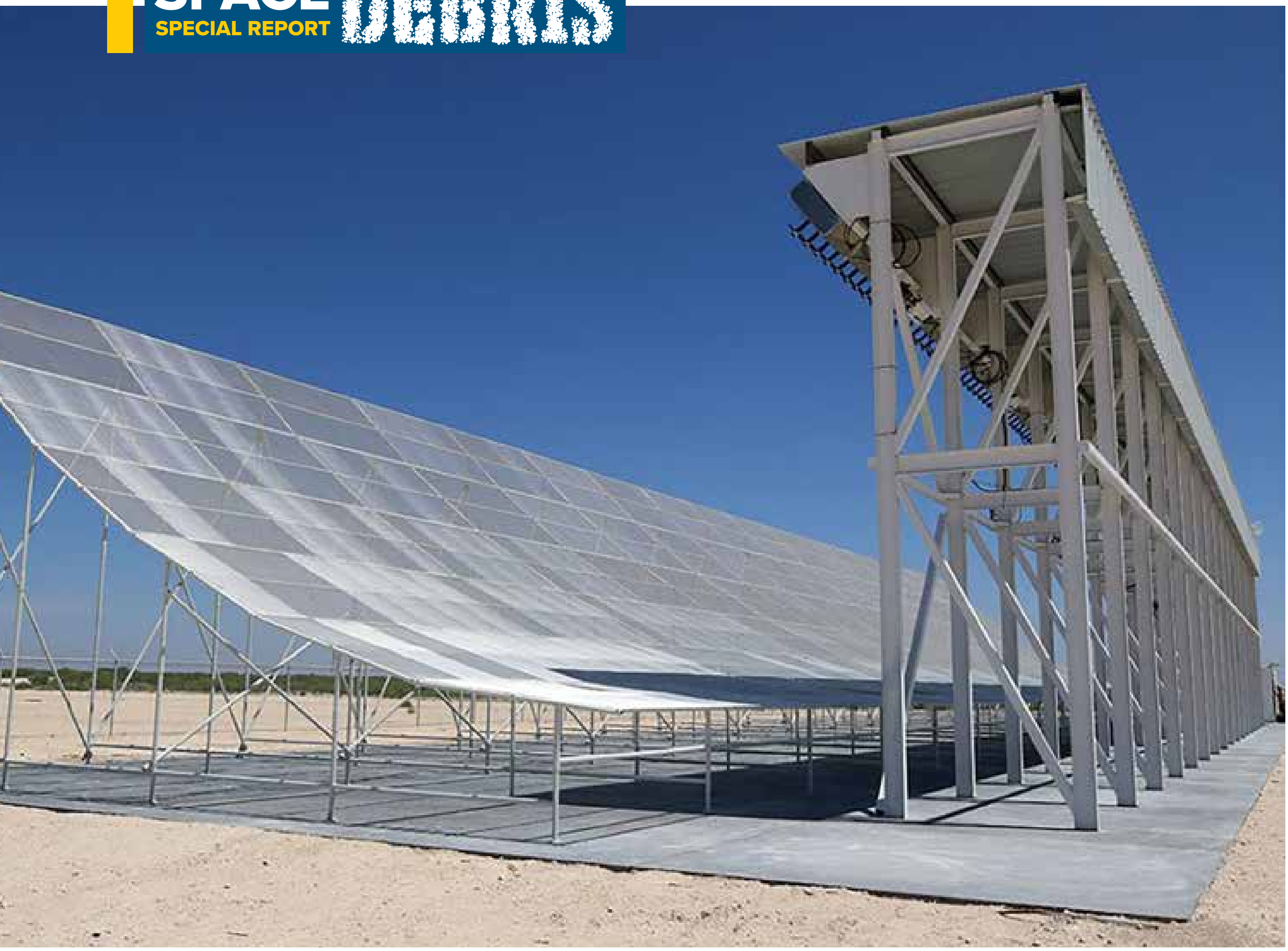
While International Space Station managers had of course thought about how to react to the possibility of a debris strike, a close call in 2009 drove home the human stakes and led to the refined procedures that were last put into action in November 2021 when debris from Russia's anti-satellite test sent astronauts and cosmonauts to shelter in their docked spacecraft. Here's an account of the 2009 close call from former NASA astronaut Sandy Magnus, in her own words.

It was mid-March, and I was nearing the end of my months of research aboard the International Space Station. A call from mission control in Houston came in over the loudspeaker on one of the communication panels, "Hey, between 11:35 and 11:45 p.m. local time we need you to go sit in the docked Soyuz capsule because we're having a red conjunction." We didn't know it at the time, but the "red" meant that there was no time to maneuver ISS out of the way of an object that was on course to enter the keep-out zone, the imaginary 25-kilometer protective box NASA maintains around ISS.

Back at NASA's Johnson Space Center in Houston a few months later, I learned that the orbital path of an old payload assist motor had been incorrectly calculated, and it was much closer to ISS than indicated by data from the catalog maintained by the U.S. Air Force.

This was the first red conjunction, so we had no set procedure. As we were nearing the time to shelter in Soyuz in case evacuation became necessary, there was still some discussion between the ground control center in Moscow and the one in Houston: Do we shut the hatches on each module to prevent a depressurization of one module from reaching the others? Do we not shut all the hatches? There's no good answer to these questions because we didn't know how big the debris was or where it might strike the station and the subsequent effect. The debate went on for a long time about the appropriate response; we ended up shutting all the hatches in the U.S. side and leaving all the hatches open on the Russian side.

Luckily, the debris did not hit the station, and we returned to the ISS from the Soyuz shortly after, but when we returned to Earth in late March our big debrief point was: "You people need to come up with a good procedure for the crew because the confusion and lack of clarity for the crew response is not acceptable." NASA's ISS operations team worked with the other ISS partners and came up with the procedure that we saw in action most recently in November after Russia's ASAT test. — *Sandy Magnus*



▲ LeoLabs currently operates four radars, including this one in Midland, Texas. The company plans to eventually operate 20 to track pieces of debris as small as 2 centimeters.

LeoLabs

focus at Privateer is on being an advocate for tackling this huge issue before it becomes too late."

At the moment, anyone can go to the Privateer website and play with an open access version of its Wayfinder software, which pools together government and industry tracking data to provide live updates about satellite and debris positions. Soon, the company hopes to start flying its own lightweight sensors in space, possibly this year, both on its own "Pono" satellites — the Hawaiian word for "do the right thing" — and those of other companies.

The sensors "can monitor 150 kilometers in any direction" via a combination of wavelengths including visible light and radar, says Fielding.

The aim is to "provide a foundational level of knowledge for the industry" so that objects are represented as more than featureless "cannonballs," explains Jah. In particular, the company plans to provide high-quality views of some of the most dangerous regions of orbit, such as where orbits come together near the poles.

Operators must also talk to each other in the event of a collision risk to decide which satellite should move. Traditionally, this has been done by phone or email, a slow and lengthy process. Slingshot Aerospace of Texas hopes to take over this burden with its Slingshot Beacon software, which carries out the conversations between subscribed operators. More than 60% of satellites in orbit are already signed up to the service since its release in August, says Melanie Stricklan, the company's CEO and co-founder.

Meanwhile, the European Space Agency is funding Neuraspace in Portugal to develop software that would automate a satellite operator's maneuver decisions, using artificial intelligence to "decrease the number of false positives and negatives," says Chiara Manfletti, Neuraspace chief operating officer. This would significantly lessen the amount of human hours spent on space traffic management.

"The idea is to make space traffic a nonissue," says Manfletti.

Removing debris

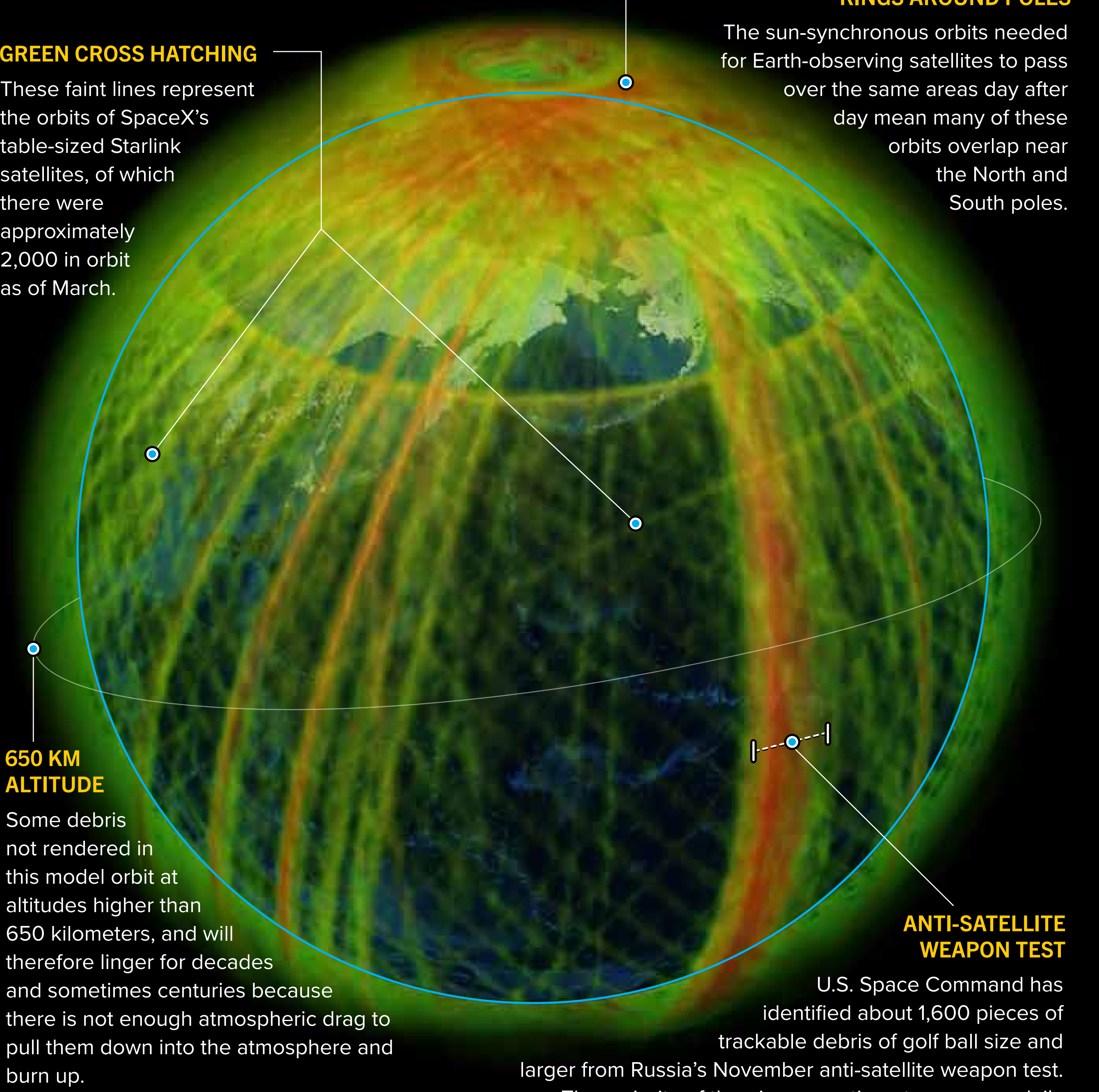
Overall, it is the dead, uncontrollable objects that could present the biggest challenge and the highest stakes. A collision between them or with an

Crowded space

Planning the orbit for a satellite is getting more and more complicated. Models such as this one by the Commercial Space Operations Center (COMSPOC), a debris tracking company, help operators determine which orbits are the most heavily populated. The shading shows areas of high density.

DEBRIS DENSITY

◂Less More▸



GREEN CROSS HATCHING

These faint lines represent the orbits of SpaceX's table-sized Starlink satellites, of which there were approximately 2,000 in orbit as of March.

RINGS AROUND POLES

The sun-synchronous orbits needed for Earth-observing satellites to pass over the same areas day after day mean many of these orbits overlap near the North and South poles.

650 KM ALTITUDE

Some debris not rendered in this model orbit at altitudes higher than 650 kilometers, and will therefore linger for decades and sometimes centuries because there is not enough atmospheric drag to pull them down into the atmosphere and burn up.

ANTI-SATELLITE WEAPON TEST

U.S. Space Command has identified about 1,600 pieces of trackable debris of golf ball size and larger from Russia's November anti-satellite weapon test. The majority of the pieces continue to progress daily around Earth, represented here by the orange band.

Graphic by David Evans, reporting by Cat Hofacker
Earth model by AGI/Ansys and COMSPOC

Low-Earth orbit as of March 14

"IT'S ONLY A MATTER OF TIME BEFORE HUMAN LIVES ARE LOST BECAUSE OF A PIECE OF GARBAGE."

— Moriba Jah, UT Austin and Privateer Space

operational satellite would suddenly present space traffic managers with hundreds or thousands of new objects that would need to be detected so that their locations in time and space, called ephemeris, can be calculated and projected into the future to warn of possible conjunctions.

This is where D'Orgeville's laser comes in, an idea almost two decades in the making. Creon Levit, formerly of NASA's Ames Research Center in California and now at the satellite firm Planet, and his colleagues were among the first to raise the concept, and it was a product of happenstance.

The year was 2009, and the Iridium-Cosmos collision had just occurred, presenting space traffic experts with an enormous ephemeris math problem. Levit's team set out to learn whether supercomputing could be applied to improve collision warnings. They spotted something unusual in the findings: Solar activity, specifically the pressure of photons radiating from the sun during its more active periods, was shifting the paths of the satellites enough to "make the difference between a collision and no collision," says Levit. "We were like, 'Wait a minute, what if we could get a laser shining on the satellite equal to the solar radiation pressure?'"

The result was LightForce, a conceptual laser that would push objects in orbit to avoid collisions. In a paper, the authors calculated that a 10-kilowatt laser would be required, making it 10 million times more powerful than a standard laser pointer and dangerous enough to send a person to the hospital. Hitting objects with such a laser a day or two before the projected conjunction would change the courses enough to remove the potential for collision.

"It looked like it would be feasible," recalls Levit.

Proposals to build a prototype were rejected, however, and the research at NASA ceased in 2015. But in Australia, D'Orgeville and her team continued the work with Craig Smith, chief technology officer of the Australian firm EOS Space Systems, who was involved in LightForce with NASA researchers. Over the next few years, they built a working prototype in a clean room at Mount Stromlo Observatory, including a less powerful "guide laser" to point the more powerful laser toward a suitable piece of space debris, such as a solar panel drifting through space. By 2019, it was ready. Unfortunately, partly because of delays caused by the pandemic, her team ran out of funding in mid-2021 before the system could be tested.

Still, if it worked, it could be used not just to nudge debris off collision courses but remove it from space entirely. "If the technology works reliably, you could increase the laser power and start thinking about pushing [debris] back down into the atmosphere," D'Orgeville says.

Such ideas remain somewhat fanciful for the time being, but there are nearer-term solutions for removing dangerous debris from orbit. One company leading that charge is Astroscale, a Tokyo-based company that wants to capture satellites with magnets and pull them back into the atmosphere. The goal is to have spacecraft ready to launch that can remove dead satellites, or even empty rocket stages, from orbit.

The company has been demonstrating aspects of the concept with a mission called ELSA-d, short for End-of-Life Service by Astroscale-demonstration, launched in March 2021. So far, the ELSA-d servicer spacecraft has made several close-range autonomous captures of a small companion satellite equipped with a metal plate that represents a future client for the service. In the coming months, ELSA-d will attempt an autonomous capture of the client from a greater distance, the ultimate goal being to capture the client while tumbling and adjust its orbital altitude.

"If that happens, it's basically demonstrating all the technologies we'll need to do an end-of-life service," says Mike Lindsay, Astroscale's chief technology officer.

OneWeb's satellites have such metal plates so that those that fail or wear out can be pulled back into the atmosphere by this technique once it's proven.

Beyond that, Astroscale has a contract with the Japan Aerospace Exploration Agency, JAXA, to perform the first large-scale debris removal in orbit. In 2025, Astroscale plans to launch a spacecraft that will sidle up to the upper section of a Japanese rocket orbiting about 600 kilometers above Earth and push it back into the atmosphere.

"We're designing a robotic arm interface to mate with it," says Lindsay. "This will be our first foray into active debris removal."

Such technology, if successful, could be invaluable. There are an astonishing number of empty rocket bodies orbiting Earth, more than 2,000 — mostly from China, Russia and the U.S. — some heavier than an elephant. If any two of these were to collide, they would produce thousands of new pieces of debris. Proposals like Astroscale's could eventually help clean up this mess.

"You would want to remove about five a year to start reducing the risk in a meaningful way," says Privateer's Jah. "You could put a bounty on [them], and governments could fuel business."

Other ideas include attaching small satellites to bring them back to life. "Put a small [satellite] on the side of it with thrusters and a receiver, and it can avoid collisions," says LeoLab's McKnight.

Taming the Wild West

The final piece of the space junk puzzle would be establishing adequate regulations. The United Nations in 2007 approved loose guidelines in hopes of controlling debris. One calls for satellites to burn up in the atmosphere no more than 25 years and to vent any remaining explosive fuel. Compliance is low, however. The 2021 Space Environment Report from the European Space Agency found that more than half of satellite operators were not following the guidelines.

Efforts are underway to put more rigorous requirements in place. Jared Zambrano-Stout, a space policy expert in Washington, D.C., was the chief of staff for the White House National Space Council in 2018 when former President Donald Trump signed Space Policy Directive-3. Among its edicts was the goal to "mitigate the effect of orbital debris on space activities."

That would include better tracking of debris but also stricter rules on satellite licensing to direct companies to better clean up their own mess in space.

"The next step is comprehensive legislation from Congress dealing with this issue," says Zambrano-Stout.

While progress has been slow, there are positive signs. During a handful of town-hall-style virtual meetings on space debris hosted by the Office of Science and Technology Policy in January to elicit comments, space executives were among those that urged the U.S. government to create stricter rules for operators and allocate funding for active debris removal demonstrations, among other actions.

"That's what's missing," Zambrano-Stout says. There are rumblings that such legislation could be on the horizon and perhaps set in stone some true rules for satellites and debris orbiting Earth in the U.S. "I think there probably is something coming," he says.

Creating global laws would be more difficult. Unless the United Nations elects to do so, it will be up to other countries to decide whether to follow in the footsteps of the U.S. And in any event, what should any potential rules stipulate?

"There's a lot of debate over that," says Weeden of the Secure World Foundation.

The 25-year deorbit guideline, for example, is "disputed by a lot of other technical experts," Weeden notes. Many experts want a shorter timeframe and also want to see a ban on anti-satellite tests, like the one Russia conducted in late 2021, to prevent large buildups of debris.

In lieu of legislation, some companies have taken it upon themselves to set their own guidelines, joining together in the Space Safety Coalition, with best practices that include removing some satellites as quickly as five years after the end of their mission — something other operators, including SpaceX with its Starlink megaconstellation, are already doing.

Weeden is among those who caution that sooner or later, however, solving the junk problem will require more stringent rules, or at the bare minimum better compliance with the existing guidelines.

Even then, regulation alone will not solve the space junk problem. Rather, it will be a multifaceted approach of tracking and removing debris, alongside holding space actors accountable when necessary. While there is a long way to go, many of the experts spoken to for this story expressed cautious optimism that all three can be achieved.

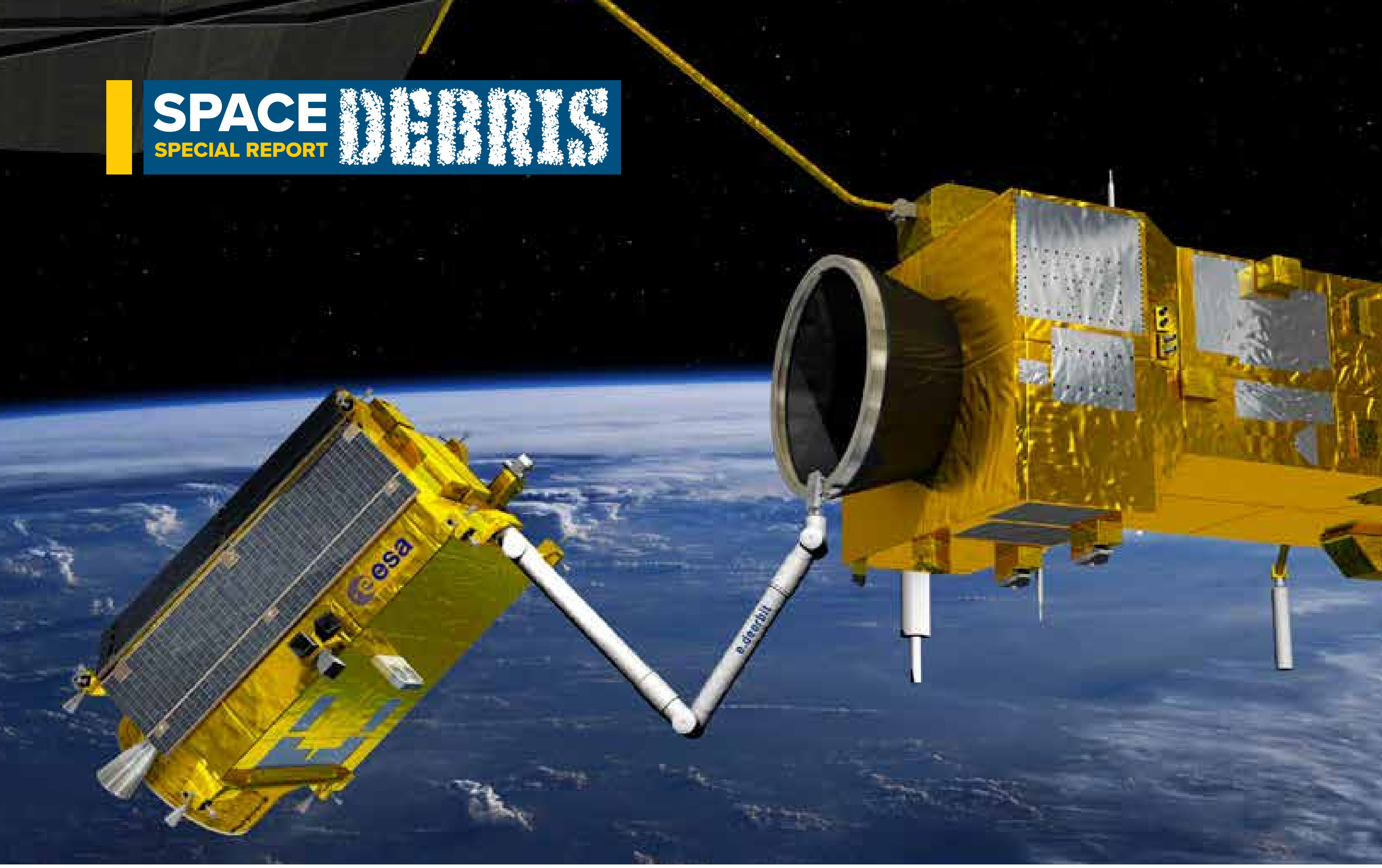
"I have every hope we can do it," says Lewis at the University of Southampton.★

SPACE DEBRIS SPECIAL REPORT

ACTIVE DEBRIS REMOVAL RULE NO. 1 MUST BE DO NO HARM

Space junk poses an existential threat to ambitious proposals to surround Earth with habitats, factories and vast constellations of satellites. What if the most dangerous debris could be grabbed and hauled out of orbit? Kerry Buckley of the MITRE Corp. offers safety advice for those who want to prove it can be done.

OPINION | BY KERRY BUCKLEY



It's a few years from now.

An obsolete satellite tumbles through low-Earth orbit end over end at 28,000 kilometers per hour. An autonomous active debris removal (ADR) tug sets up a rendezvous and begins matching the spin rate. At the right moment, it captures the tumbling satellite. Once it has gained complete control, the ADR tug slows the satellite to lower its altitude and releases it to burn up in the atmosphere.

That's an ideal scenario.

In the worst case, the ADR tug collides with the satellite and creates a 15-kilometer-wide debris field that not only closes off a valuable orbit for decades but also accelerates the Kessler Syndrome of cascading collisions, wiping out numerous communications, surveillance, and scientific satellites.

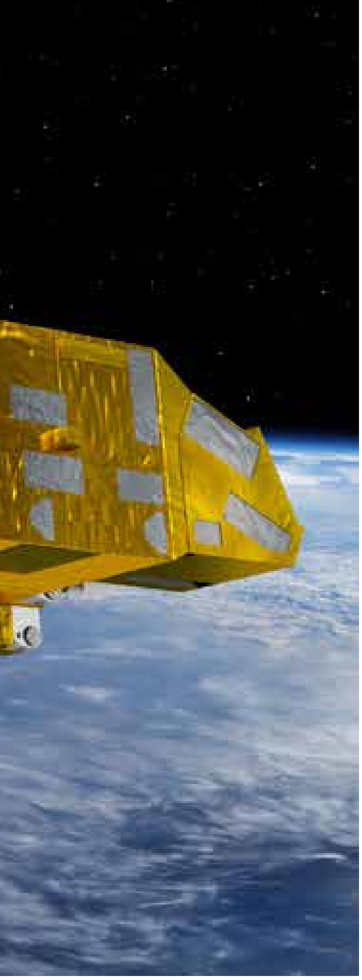
These days, there's a lot of buzz about ADR, and I can appreciate why. ADR has the potential to help solve a massive problem and be very lucrative in the process. Unfortunately, the challenges of ADR are probably harder than many people realize, and the ramifications of failure are also likely higher than most suspect. So, before any demonstrations in space, companies on the cutting edge of ADR need to borrow from the Hippocratic oath and "first, do no harm."

Ultimately, there should be many federal, industry and international organizations involved in establishing the safety standards and regulation of ADR. Yet right now, this capability is accelerating in the absence of regulation. To minimize the negative impacts of space debris, those on the cutting edge of ADR must — at a minimum — take a cue from the aviation and nuclear sectors by establishing a safety management system.

An SMS provides a framework for achieving an acceptable level of risk. Each SMS is built on four foundational pillars: **safety policy, safety risk management, safety assurance, and safety promotion.**

To illustrate how this would work in space, let's build an imaginary company on the cutting edge of ADR. Let's assume that you and an SMS-trained friend want to start an ADR company. First, you need to decide what "active debris removal" means in your company.

ADR means different things to different people, and this can lead to confusing risk and consequence discussions between internal decision-makers, potential customers and operational orbital neighbors. In entrepreneurial terms, the ADR definition is directly related to the "why" for the company and provides a tangible yardstick for success. For instance, you could do anything from a) moving debris into orbit to burn up, b) taking it to high orbits to leave in "graveyards" or c) repurposing debris — everything from refueling and minor upgrades to recycling the materials on orbit. Each of these disparate missions has unique risks, so be sure your company doesn't act as if they are all the same.



"Active debris removal is without a doubt an extremely complex challenge. Yet, given the right resources and effort, it's achievable, so long as the ramifications of failure are always kept in mind."

— Kerry Buckley, the MITRE Corp.

▲ The European Space Agency's risk assessments for its now-canceled active debris removal demonstration included the likelihood of the e.Deorbit satellite, left, shattering the defunct Envisat environmental satellite when grasping it via robotic arm. ESA ultimately decided to further develop the e.Deorbit design for a broader range of satellite servicing tasks, including refueling satellites and dragging them to lower altitudes to deorbit.

European Space Agency

Imprecise communication cripples the ability to make data-driven decisions.

You arrive at the following concrete definition of ADR for your company: XYZ Corporation will apposition a grappler satellite to capture defunct satellites weighing less than 1,000 kilograms and orbiting no more than 1,000 km above Earth and relocate them to a near-term reentry orbit at 300 km. Afterward, the grappler will recover to a working altitude of 500 km.

With ADR defined, here's how your SMS implementation should play out:

1 Start with safety policy, the first pillar of SMS

The top safety objective for every ADR company should be "first, do no harm." This should drive your vision for ADR and serve as a focal point for risk-based decision making. After laying this foundation, you can develop the rest of the safety policy, including a nonpunitive safety reporting system.

2 Apply safety risk management to your business operations

Applying safety risk management means asking the hard questions, identifying hazards and analyzing and controlling risks to provide the highest probability of mission success.

Fast-forward a bit: Your team has been hard at work applying safety risk management to make sure your grappler design can complete the ADR mission you defined. Finally, a big government contract you've anticipated opens for bids to remove a piece of debris. This is your chance to impress the world and literally get your work off the ground. The contract provides three candidate debris objects: two rocket bodies at 850 km and one defunct satellite at 600 km. Which should you choose?

The board meeting to decide on the bid specifics is electric; everyone is excited. The rocket bodies are big, tempting targets, and rescaling your grappler is probably doable on the timeline. You really want to go after those rocket bodies, but your friend takes over the room by applying safety risk management and pointing back to your top safety objective: To first do no harm, you must first know that your technology will work. The rocket bodies still contain fuel, so the risk of explosion is too high. Therefore, your proposal must target the defunct satellite, enabling you to mature your technology and operations. Everyone leaves in agreement, recognizing that even for the defunct satellite disposal, there are many challenges to overcome.

Fast-forward another few months, and your application of safety risk management is bearing fruit. Your most junior engineer uses the safety reporting system after two days on the job to point out a critical design flaw, saving the mission. You've chopped down that long list of open-ended questions and unmitigated risks, and evidence pointing to a successful mission is piling up. You've made some momentous achievements:

- Developed a new way to determine and match the tumble of the satellite
- Performed countless simulations showing that your grappler, Grappler-1, will successfully capture, despin and control the satellite
- Simulated control of the satellite even if one of your thrusters fails midoperation
- Verified that you have enough Delta-V (change in velocity) to regain station at 500 km and perform another similar disposal before retiring Grappler-1

You've also developed some robust risk mitigations, such as:

- Perfecting the close-approach procedure without making accidental contact (and along the way, producing a few patentable technologies)
- Requiring the capture maneuver to occur below 30 degrees latitude to ensure dependable connectivity with your ground stations
- Protecting Grappler-1 and your distributed network components from malicious actors and tampering by implementing a zero-trust cyber architecture that allows only authorized users to interface with the spacecraft

Armed with your digital mountain of safety risk management-derived evidence of success, you breeze through the final contracting process and are officially on the path to being well compensated and on the clock to remove the defunct satellite. Now your SMS will really be tested.

3 Safety assurance, the bedrock of successful ADR operations

Your company has grown, hiring is at an all-time high, and everyone is working full steam on finishing Grappler-1 to fly on your scheduled launch date. Working at this pace, it's easy to lose track of safety, which is why your first hire after landing the contract was a dedicated safety assurance manager — let's call her Sam.

- Sam makes sure everyone is complying with the policies, plans and procedures you developed by applying safety risk management to develop your contract proposal, and she's helping the company perform even better than you initially planned. Sam uses data analysis methods, spotting performance trends and employing training improvements to prevent problems before they happen. The company sails through construction smoothly.
- During pre-launch rehearsals, Sam proves even more valuable. She notices one of the operating teams is not performing as required and provides insights, allowing you to reshuffle the teams for optimum performance.
- Of course, there is one launch delay: a pop-up thunderstorm that wastes a short launch window.
- The new operating teams then notice that there's an unreliable data link in the South Pacific and report it up to Sam, kicking off a safety risk management review process that develops an additional operational restriction on the capture maneuver to maximize the reliability of the control signal. It means delaying the capture by a day, but looking back to "first, do no harm," it is an easy delay to accept.
- The mission is flawless, and after returning Grappler-1 to the 500-km loitering orbit, you get calls from four governments wanting to hire your company for the next mission. It's the best day of your career.

4 Safety promotion — a pillar and a product

Because you did this SMS implementation right, it's now become the foundation for how you do business, and the safety culture at the employee level is tangible. Sam trains a great replacement and tells you her next job will be at the United Nations, promoting safety as the key to expanded space operations on an international level. Sam says that the safe and successful ADR work done at your company was the key to developing international consensus that ADR is safe and viable. She hopes from there to develop consensus that enables answering the most challenging ADR question of all: Who can actually authorize removing the spent Soviet rocket bodies trapped in low-Earth orbit?

Congratulations! You've done it. Your company has a bright future, investors and customers are lining up, and there are rumblings about a Draper Prize. How did you get there? By building an ADR enterprise on SMS principles, overcoming challenges and producing amazing results through a repeatable safety process.

Jumping back to reality from this imaginary company, ADR is without a doubt an extremely complex challenge. Yet, given the right resources and effort, it's achievable, so long as the ramifications of failure are always kept in mind. We must learn from other high-consequence industries and build on a foundation of SMS, making sure to first do no harm. ★

Kerry Buckley is vice president for air and space forces at the MITRE Corp., which operates multiple U.S. government-funded research centers. She holds a doctorate in industrial and organizational psychology from George Washington University.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Gambling on advanced air mobility

Funds and pledges of funding have been pouring in from large corporations to a handful of small companies that are pioneering a proposed new mode of transportation for average people. Does the investment trend guarantee that this class of electric-powered rotorcraft will soon take off with us aboard? Aaron Karp spoke to the industry executives who should know.

BY AARON KARP | aaronkarp74@gmail.com

It is a seductive vision of the future of short-haul transport: Perhaps as soon as 2024, people will be able to commute to work or head to the airport via electric-powered air taxis flying over the congestion of large metropolitan areas. By the 2030s, these aircraft would be ubiquitous (and, in many cases, remotely piloted), giving a wide swath of the population access to the most modern of transportation services.

But is this vision realistic? A broad spectrum of corporations seem to have answered "yes" by pledging billions of dollars for development over the past two years and making commitments to buy or lease thousands of this proposed new breed of aircraft. A closer look shows an industry whose executives often readily acknowledge that they are taking a gamble, with not everyone convinced it will prove to be a worthy one.

$10 billion investment

Most plans call for electric vertical takeoff and landing, or eVTOL, designs, and in fact the figurative order book for eVTOLs stretches to at least 3,600 units, according to AirInsight Group, a consultancy with offices in Detroit and Washington, D.C., that tracks eVTOL commitments. For now, these are all provisional orders from a who's who of corporations around the globe, and acting on those orders depends on manufacturers earning certifications from FAA, the European Union Aviation Safety Agency and Japan's Civil Aviation Bureau.

Investors include major airlines, the world's three largest commercial aircraft manufacturers, automobile companies, ride-share corporations and technology firms. They are selling their stockholders on the idea that this nascent technology is aviation's next evolutionary step. At first, flights are expected to be in the 40- to 80-kilometer range and expand to around 160 km as engineers and scientists improve the technology.

In 2021 alone, investment pledges in the eVTOL sector topped $5 billion, as much as the previous five years combined, according to the Vertical Flight Society, a Fairfax, Virginia-based technical organization.

Among them, American Airlines last year acquired 11,250,000 shares of eVTOL developer Vertical Aerospace of Bristol in the U.K., making the airline a holder of 5.4% of Vertical's equity, according to a U.S. Securities and Exchange Commission filing. American's $25 million investment in Vertical was done through a private investment in public equity transaction, or PIPE, which means the airline acquired the shares directly from Vertical instead of via the stock market. American also placed a provisional order for 250 of Vertical's VX4 eVTOL aircraft, a four-passenger-plus-pilot design whose first flight could come this year.

Mathew Sebastian, American Airlines' managing director of corporate development and planning, says American "100% believes" in the potential of eVTOLs, adding that the world's largest airline is just one of a number that have ordered air taxi rotorcraft.

My review of public announcements shows that globally, 10 passenger airlines have placed provisional orders or committed to leasing agreements for eVTOLs.

For instance, in addition to American, Vertical's roster of equity holders includes Virgin Atlantic Airways.

"Airlines believe that our model is realistic," Eduardo Dominguez Puerta, Vertical's chief commercial officer, told me in an interview.

▲ AirAsia, best known for shuttling passengers around South Asia in jets, wants to fly passengers around urban areas in VX4 electric aircraft, shown here in a rendering. Plans call for leasing 100 or more of the electrical vertical takeoff and landing aircraft, to be made by Vertical Aerospace of Bristol in the United Kingdom, through the Irish leasing firm Avolon Aerospace.

Avolon Aerospace

Perhaps Vertical's most important investor is Irish commercial aircraft leasing giant Avolon Aerospace, which has not only placed a provisional order for 500 VX4s but has also announced leasing deals with airlines for 450 of those 500 aircraft. As part of Avolon's 2021 agreement to become an equity holder in Vertical, it provided $15 million to Vertical, and Avolon CEO Dómhnal Slattery is now the chairman of Vertical's board of directors.

"The eVTOL market has definitely benefited from the inflow of capital," says Marc Tembleque Vilalta, a vice president for airline analysis at Avolon-e, the company's unit managing eVTOLs. "Why now? We believe this is going to be a supply-constrained market for some time, so timing is critical."

At the Singapore Airshow in February, Avolon made a splash by announcing a provisional leasing agreement with AirAsia for 100 of its 500 VX4 aircraft. The Malaysia-based low-cost airline has one of southeast Asia's most extensive passenger networks.

Target markets

Companies developing eVTOLs for what has come to be known as advanced air mobility or urban air mobility see three primary potential use cases:

- Shuttling airline passengers to and from airports and between airports in cities that have multiple airports, such as New York and London.
- Carrying commuters to their offices. For these customers, Joby Aviation of California plans to take advantage of structures that suburban residents know well. "Parking garages have a lot of the characteristics you need — places for customers to park with big flat tops," says Eric Allison, Joby's head of product. Joby has a partnership agreement with REEF Technology and Neighborhood Property Group, a Miami-based parking lot owner and operator, to jointly develop rooftop "skyports." Commuters would park at these suburban garages and then go to the roof to catch eVTOL flights to the city center.
- Linking nearby cities with each other or linking islands

in places like Hawaii. Developers generally concede this eVTOL application will likely be added once the first two uses are established.

Airlines say that their greatest interest, at least initially, is to give passengers a means to get to airports faster.

"For example, you could connect San Francisco International Airport with suburbs that now require a very long drive," says Michael Whitaker, the chief commercial officer of Supernal, the eVTOL arm of South Korea's Hyundai Motor Co.

Supernal, which was launched in November 2021, aims to have its eVTOL enter commercial service in 2028. As an automaker, Hyundai will be able to develop an automobile-style assembly line manufacturing process for eVTOLs, adds Whitaker.

The world's biggest aircraft manufacturers have also thrown their monetary support behind the

Big money for small aircraft

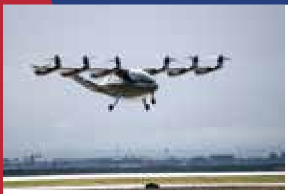
With few exceptions, early entries in the market for electric vertical takeoff and landing aircraft are reliant on outside investors for the money needed to design, build and certify their aircraft. The exceptions include Airbus Group and Hyundai Motor Corp., which have chosen to internally fund development of their eVTOLs. Here's where airlines and investors are placing their bets.

*A SPAC is created for the sole purpose of raising funds through an initial public offering to purchase or merge with another company. After the merger, the SPAC is effectively dissolved, and the company can use the funds to develop its product.

Graphic by Thor Design, reporting by Aaron Karp

Sources: SMG Consulting, Aerospace America research

COMPANY



Archer Aviation of Silicon Valley

Eve Urban Air Mobility Solutions of Brazil

Joby Aviation of California

Lilium of Germany

Vertical Aerospace of the U.K.

Volocopter of Germany

Wisk Aero of Silicon Valley

eVTOL industry, believing their experience certifying and bringing new airplanes into service will provide an advantage over automobile manufacturers and other developers.

Boeing has pledged $450 million in a series of installments to Silicon Valley eVTOL developer Wisk Aero, which aims to begin passenger flights with its remotely piloted eVTOL design by the end of this decade. Boeing plans to partner with Wisk in all aspects of development. Airbus is experimenting with its own prospective eVTOL design called CityAirbus NextGen. And Brazil's Embraer, the third largest commercial aircraft manufacturer in the world, has established Eve, a subsidiary charged with developing an eVTOL.

Keeping perspective

"There's a lot of momentum around eVTOLs," Airbus Group CEO Guillaume Faury said during a February

AIRCRAFT	PASSENGERS	FUNDING
Maker, a two-seat demonstrator, is conducting test flights	4	• Raised a combined $857.6 million from private investors and a September merger with Atlas Crest Investment Corp., a special purpose acquisition company or SPAC* • United Airlines in early 2021 announced a provisional $1 billion order for 200 Archer eVTOLs, with the option to purchase an additional 100
Eve	4	• The Former Embraer subsidiary in December raised a combined $542 million from private investment from companies including Embraer and a planned merger with Zanite Acquisition Corp., a special purpose acquisition company or SPAC* • Announced that 17 customers as of late 2021 had signed non-binding letters of intent to purchase eVTOLs, including Republic Airways for 200 eVTOLs and SkyWest Airlines for 100 eVTOLs
S4-2, a four-seat prototype, is conducting test flights	4	• Raised $1.6 billion in August from private investment and a merger with Reinvent Technology Partners, a special purpose acquisition company or SPAC* • Uber has invested $125 million in Joby as of late 2020, when the California company acquired Uber's air taxi division • Toyota Motor Corp. in early 2020 said it had invested $394 million and will advise Joby in setting up its eVTOL manufacturing facility
Lilium Jet	6	• Raised $584 million after a September merger with Qell Acquisition Corp., a special purpose acquisition company or SPAC* • Azul Brazilian Airways in 2021 announced an agreement to buy 220 Lilium Jets, a $1 billion transaction • Honeywell in June 2021 announced an unspecified investment in Lilium and that it would provide the fly-by-wire, flight controls and custom avionics for Lilium Jets
VX4	4	• Raised $300 million after a December merger with Broadstone Acquisition Corp., a special purpose acquisition company or SPAC* • American Airlines in June 2021 said it planned to invest $25 billion and pre-order 250 VX4s, worth about $1 billion • Irish aircraft leaser Avolon Aerospace in 2021 said it will invest $15 billion and preorder 500 VX4s, valued at about $2 billion
VoloCity	2	• Volocopter in March announced a $170million Series E funding round led by Korean firm WP Investment • Geely Technology Group of China in September 2021 signed an agreement to purchase 150 eVTOLs • Japan Airlines invested an undisclosed amount in Volocopter in 2020
Cora, a two-seat demonstrator, is conducting test flights	TBD	• Boeing in February pledged $450 million, to be paid in installments • Wisk in May 2021 announced it would fly 30 of its eVTOLs for Blade, a Delaware company creating an advanced air mobility network with flights operated by third parties

▲ Airbus is rare among jet makers for developing its electric rotorcraft in-house instead of creating a devoted subsidiary or investing in another company's aircraft. Airbus last year released a rendering of its planned CityAirbus NextGen air taxi (right), the design for which was loosely based on its four-seat CityAirbus demonstrator. The four ducted propellers in the original concept, which made dozens of test flights between 2019 and 2021, were swapped for six propellers arranged on the trailing edge and front of the wing. A V-shaped tail was added with two propellers atop it.

Airbus

virtual press conference to discuss the company's annual earnings. "I can only welcome this appetite for eVTOLs."

However, he cautioned against excessive exuberance. "A lot needs to happen before we have a market that starts to create revenues and margins," Faury said. "There's still development needed on the technology, on the certification process, on the regulations for operations. We're investing at Airbus. We see many others investing."

He added: "But I believe there still is work to be done before we come to real commercial operations."

Indeed, skeptics point out that the only way for the fledgling sector to generate a sizable profit would be to manufacture aircraft at a massive scale that will be difficult to achieve — at least for the foreseeable future. While eVTOL developers and investors tout the anticipated low per-trip operating cost of the battery-powered rotorcraft, Richard Aboulafia, the managing director of Washington, D.C.-based AeroDynamic Advisory, has said the per-aircraft production cost is expected to be in the $4 million to $5 million range, at least initially.

"I don't often get exclusive use of a $5 million machine," he tells me, noting that eVTOL operators are developing aircraft to carry just one to four passengers per trip. "Everyone is so focused on operating costs that they forget about capital costs."

Aboulafia believes anything other than a limited market for high-end passengers in select cities such as São Paulo, Brazil, is unrealistic this decade. He is critical of Boeing's investment in Wisk, saying it is far afield from the manufacturer's core aircraft manufacturing business, which has been plagued with high-profile technology and manufacturing issues in recent years on its 737 MAX and 787 Dreamliner programs.

"How does it impact their core business at all?" Aboulafia wonders aloud. "About 1% of Boeing's business, at the most, relates to flights of less than 500 miles, let alone 25-50 miles. What's the relevance here?"

Aboulafia cautions that eVTOL investment and order announcements should be taken with a grain of salt, noting most of the money is pledged rather than paid and the orders are all provisional.

eVTOL developers, while generally confident in the technology, do acknowledge serious challenges ahead. Whitaker of Supernal notes that an entire operational infrastructure also needs to be established. Vertiports have to be built and be plentiful enough that consumers do not have to drive too far to reach a takeoff spot, which would of course defeat the purpose of flying. Also needed are numerous eVTOL charging stations.

"If you're manufacturing cars, you don't have to worry about roads and gas stations," he says. "We don't have any of that."

Pressed by a reporter at the February earnings press conference about the wisdom of Airbus investing in "speculative" technology, Faury said that even if commercial eVTOL services do not come to fruition until the distant future, research on electric batteries would be applicable to the next-generation airplanes coming to market in the 2030s.

"It makes a lot of sense for us to be part of the eVTOL ecosystem," he said.

Boeing has similarly said its investment in eVTOLs is part of a wider sustainability strategy. "We are always looking for ways to reduce our environmental impact," Heidi Hauf, Boeing's Asia-Pacific sustainability lead, tells me.

Executives, particularly those at eVTOL companies, remain confident about the commercial viability of the technology. One of them is Vilalta, the Avolon-e vice president.

"The value proposition for passengers is very high when you look at the time they will be saving," he

says. "And eVTOLs will be much simpler to maintain" than conventional aircraft, "which takes a lot of the cost out right there."

However, he says eVTOLs entering service this decade will be mostly limited to high-end passengers able to pay a premium. "There's going to be a phase initially where OEMs are not going to be able to produce at scale, and demand will outstrip supply."

That means the faster developers can get aircraft to market, the faster they can move through the costly proving period.

"We're not doing this to develop a premium service only for high-end passengers," Wisk CEO Gary Gysin says.

Joby, which early this year had two prototype aircraft in flight testing, believes it can achieve certification in time to begin passenger flights in 2024 with its four-passenger piloted aircraft. It has already started the FAA certification process. The company had a setback on Feb. 16 when one of its prototype eVTOLs — the same model Joby plans to bring to service, but in this case flown remotely without an onboard pilot — crashed during flight testing in California. There were no injuries, but a preliminary report from the U.S. National Transportation Safety Board said the aircraft was "substantially damaged."

Allison says Joby expects to "rapidly scale" production and operations once its aircraft enters commercial service. Joby plans to be the OEM and operator of the vast majority of its eVTOL aircraft. Toyota Motor Corp. is Joby's leading equity holder, investing $394 million in the company.

Also, Joby, Toyota and Tokyo-based All Nippon Airways entered into a partnership in February to develop an eVTOL market in Japan, with an important distinction.

"ANA is not investing any money in Joby, and the relationship with Joby is simply a partnership to begin studying the potential of air mobility in the Japanese market," Yuki Horie, the project director of ANA's Digital Design Lab that explores future transportation technology, tells me by email. "We are targeting the introduction of eVTOL aircraft in Japan by around 2025, but whether this will be for commercial use is yet to be decided."

> "A lot needs to happen before we have a market that starts to generate revenues and margins. There's still development needed on the technology, on the certification process, on the regulations for operations."
>
> **— Guillaume Faury, Airbus Group**

Advanced air mobility firms are counting on the public to grasp the potential of eVTOLs and warm to the technology. "From our perspective, it's almost like being in the 1980s with the advent of the desktop computer," Superal's Whitaker says. "I think it's that kind of innovation. It will be a metro rail system in the air."

How has all this investment changed the sector? In the view of Vertical's Puerta, the investments contributed to whittling down a field of dozens of prospective players to half a dozen or so with the financial backing to have credible hopes of succeeding.

"Investors have made their bets," he says. ★

AIAA Bulletin

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Calendar

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2022			
29 Mar–7 Apr	Technical Writing Essentials for Engineers Course	ONLINE (learning.aiaa.org)	
1–2 Apr	AIAA Region IV Student Conference	San Antonio, TX	31 Jan 22
1–3 Apr	AIAA Region VI Student Conference	Merced, CA	5 Feb 22
4–5 Apr	AIAA Region II Student Conference	Atlanta, GA	4 Feb 22
4–6 Apr*	3rd IAA Conference on Space Situational Awareness (ICSSA)	Madrid (http://reg.conferences.dce.ufl.edu/ICSSA)	
4–14 Apr	Fundamentals of Data and Information Fusion for Aerospace Systems Course	ONLINE (learning.aiaa.org)	
8–9 Apr	AIAA Region V Student Conference	Colorado Springs, CO, & Online	13 Feb 22
11 Apr–18 May	Design of Space Launch Vehicles Course	ONLINE (learning.aiaa.org)	
12–21 Apr	Application of Thermal Vacuum Testing Course	ONLINE (learning.aiaa.org)	
19–21 Apr	AIAA DEFENSE Forum	Laurel, MD	19 Oct 21
21–24 Apr	AIAA Design/Build/Fly	Wichita, KS	
22 Apr	Non-Intrusive Laser-Based Diagnostic Techniques for Hypersonic Flows Course	Laurel, MD (aiaa.org/defense)	
26 Apr	AIAA Fellows Induction Ceremony and Dinner	Arlington, VA	
26–29 Apr	Applied Model-Based Systems Engineering Course	ONLINE (learning.aiaa.org)	
27 Apr	AIAA Awards Gala	Washington, DC	
27–28 Apr	ASCENDxTexas: Accelerating the Business of Space Exploration Moving Beyond the Now	Houston, TX (ascend.events/ascendx)	
2–5 May	Applied Space Systems Engineering Course	ONLINE (learning.aiaa.org)	
3–4 May	OpenFOAM CFD Foundations Course	ONLINE (learning.aiaa.org)	
3–5 May*	6th CEAS Conference on Guidance, Navigation and Control (EuroGNC)	Berlin, Germany (eurognc2022.dglr.de)	31 Oct 21
4–27 May	Electrochemical Energy Systems for Electrified Aircraft Propulsion Course	ONLINE (learning.aiaa.org)	
10 May–30 Jun	Human Spaceflight Operations: Lessons Learned from 60 Years in Space Course	ONLINE (learning.aiaa.org)	
12–13 May*	AIAA SOSTC Improving Space Operations Workshop 2022	Virtual Event (https://isow.space.swri.edu)	
16–19 May*	26th Aerodynamic Decelerator Systems Technology Conference and Seminar (ADSTCS)	Toulouse, France (https://earthlydynamics.com/adst-2022)	
17–26 May	Digital Engineering Fundamentals Course	ONLINE (learning.aiaa.org)	

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

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2022			
24–25 May	OpenFOAM External Aerodynamics Course	ONLINE (learning.aiaa.org)	
6–9 Jun	Designing Space Missions Course	ONLINE (learning.aiaa.org)	
7 Jun	OpenFOAM CFD Aeroacoustics Course	ONLINE (learning.aiaa.org)	
8 Jun	OpenFOAM CFD Dynamic Mesh Modeling Course	ONLINE (learning.aiaa.org)	
14–17 Jun*	28th AIAA/CEAS Aeroacoustics Conference	Southampton, UK (aeroacoustics2022.org)	12 Jan 22
15 Jun–10 Aug	Missile Design: A Comprehensive Guide to Propulsion, Aerodynamics, Weight, Flight Performance, Guidance, Lethality, System Engineering, and Development Course	ONLINE (learning.aiaa.org)	
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	
26 Jun	2nd AIAA Workshop for Multifidelity Modeling in Support of Design & Uncertainty Quantification	Chicago, IL	
27 Jun–1 Jul	AIAA AVIATION Forum	Chicago, IL	10 Nov 21
16–24 Jul*	44th Scientific Assembly of the Committee on Space Research and Associate Events (COSPAR)	Athens, Greece (cospar-assembly.org)	11 Feb 22
19 Jul–11 Aug	Design of Electrified Propulsion Aircraft Course	ONLINE (learning.aiaa.org)	
7–10 Aug*	AAS/AIAA Astrodynamics Specialist Conference	Charlotte, NC	1 Apr 22
4–9 Sep*	33rd Congress of the International Council of the Aeronautical Sciences (ICAS 2022)	Stockholm, Sweden (icas2022.com)	10 Feb 22
18–22 Sep*	73rd International Astronautical Congress	Paris, France (iac2022.org)	
24–26 Oct	ASCEND Powered by AIAA	Las Vegas, NV	31 Mar 22
2023			
23–27 Jan	AIAA SciTech Forum	National Harbor, MD	1 Jun 22
11–13 Apr	AIAA DEFENSE Forum	Laurel, MD	Aug 22
12–16 Jun	AIAA AVIATION Forum	San Diego, CA	
2–6 Oct*	74th International Astronautical Congress	Baku, Azerbaijan (iac2023.org)	
23–25 Oct	ASCEND Powered by AIAA	Las Vegas, NV	

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

● AIAA Continuing Education offerings

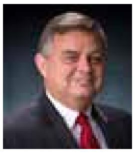
Recognizing Top Achievements an AIAA Tradition

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 re-imagine 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 2021 and January 2022.

Presented at ASCEND, 15–17 November 2021, Las Vegas, NV

2021 von Kármán Lectureship in Astronautics



David M. Van Wie
Johns Hopkins University Applied Physics Laboratory
Lecture: "Multi-Domain Convergence of Space and Near-Space"

2021 David W. Thompson Lecture in Space Commerce Award

Walter Scott
Maxar
Lecture: *"Birth of the Remote Sensing Industry"*

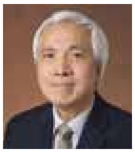
2021 AIAA Hypersonic Systems and Technologies Award

Steven H. Walker
Lockheed Martin Corporation
For outstanding leadership in the furthering of Hypersonic Technology by initiating and managing novel flight demonstrators providing the maturity necessary to transition to operational systems

2021 AIAA Space Systems Award

Ingenuity Mars Helicopter Team
Accepting: Håvard F. Grip, NASA Jet Propulsion Laboratory
For the design and flight test validation of the first helicopter designed for flight at Mars

2021 AIAA von Braun Award for Excellence in Space Program Management

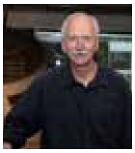


Fuk K. Li
NASA Jet Propulsion Laboratory
For sustained excellence in management of NASA's New Millennium and Mars Exploration Programs, achieving major breakthroughs in space technology and Mars exploration objectives

Presented at AIAA SciTech Forum, 3–7 January 2022, San Diego, CA

LECTURESHIPS

2022 AIAA Durand Lecture for Public Service



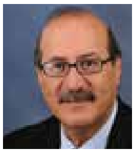
William H. Gerstenmaier
SpaceX
Lecture: "Human Spaceflight — The Ultimate Team Sport"

2022 AIAA Dryden Lectureship in Research

Anthony M. Waas
University of Michigan, Ann Arbor
Lecture: "Digital Tools for Design and Analysis of Composite Aerostructures"

EDUCATION AWARD

2021 J. Leland Atwood Award



Saeed Farokhi
University of Kansas
For outstanding and consistent contributions to the aerospace profession especially in the areas of propulsion and high-speed aerodynamics, and a profound and long-lasting commitment to the education, mentorship, and professional development of both graduate and undergraduate aerospace engineering students.

LITERARY AWARDS

2022 Gardner-Lasser Aerospace History Literature Award

John M. Logsdon
Space Policy Institute, George Washington University
Book: *Ronald Reagan and the Space Frontier*

2022 AIAA Summerfield Book Award

Don L. Edberg
California State Polytechnic Institute, Pomona
Book: *Design of Rockets and Space Launch Vehicles*

Willie Costa
VUONG Global
Book: *Design of Rockets and Space Launch Vehicles*

SERVICE AWARD

2022 AIAA Diversity and Inclusion Award

Eric B. Holmes
NASA Headquarters
For sustained significant contributions to raise awareness on the value of diversity and inclusion in the aerospace workforce at large, an AIAA core value.

TECHNICAL AWARDS

2022 AIAA Aerodynamic Measurement Technology Award

Noel T. Clemens
University of Texas at Austin
For the development and application of innovative laser-based imaging techniques to bring new insight into the physics of complex turbulent flows.

2022 AIAA Aerospace Design Engineering Award

Michael Buonanno
Lockheed Martin Aeronautics
For design innovation and engineering leadership in the development of X-59, the Quiet Supersonic Technology X-plane.

2022 AIAA Aerospace Guidance, Navigation and Control Award

Siva S. Banda
Air Force Research Laboratory (retired)
For outstanding and sustained contributions to advancing flight control theory and its applications.

2022 AIAA Air Breathing Propulsion Award

Srinath V. Ekkad
North Carolina State University
For significant technical contributions to the development of pioneering detailed heat transfer measurements inside gas turbines and continued leadership in the aerospace community to develop new industry-university partnerships.

2022 AIAA de Florez Award for Flight Simulation

Sunjoo K. Advani
International Development of Technology B.V.
For his exceptional impacts on simulation science, particularly in the worldwide implementation of objective measures of the quality of flight simulation motion systems.

2022 AIAA Energy Systems Award

George Crabtree
University of Illinois Chicago/Argonne National Laboratory
For his seminal contributions to defining the next-generation energy system and innovative technological and workforce development pathways to achieve it.

2022 AIAA Intelligent Systems Award

Ella M. Atkins
University of Michigan
For outstanding, creative, interdisciplinary solutions in the theory and deployment of intelligent autonomous aerospace vehicles over the past two decades.

2022 AIAA Mechanics and Control of Flight Award

Mark L. Psiaki
Virginia Polytechnic Institute and State University
For the development of new nonlinear estimation algorithms and for their application to problems in satellite attitude and orbit determination and in GPS signal processing.

2022 AIAA Microgravity and Space Processes Award

Carlos Fernandez-Pello
University of California, Berkeley
For decades of microgravity research in smoldering, flame spread and spacecraft fire safety and for leadership in the microgravity research community.

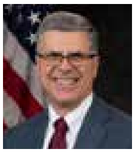
2022 AIAA Propellants and Combustion Award

Tim C. Lieuwen
Georgia Institute of Technology
For outstanding leadership in research and development of high-performance, fuel-flexible power and propulsion combustion technologies.

2022 AIAA Survivability Award

Alex G. Kurtz
Survivability Assessment Flight, Aerospace Survivability and Safety Office, 704th Test Group, USAF (retired)
For distinguished service and contributions to the aircraft/aerospace survivability/vulnerability community and discipline.

2022 AIAA Wyld Propulsion Award



Daniel J. Dorney
NASA Marshall Space Flight Center
For his leadership, sustained contributions, and outstanding dedication to the design, development, testing, and operation of propulsion systems critical to our nation's future in space.

2022 ICME PRIZE

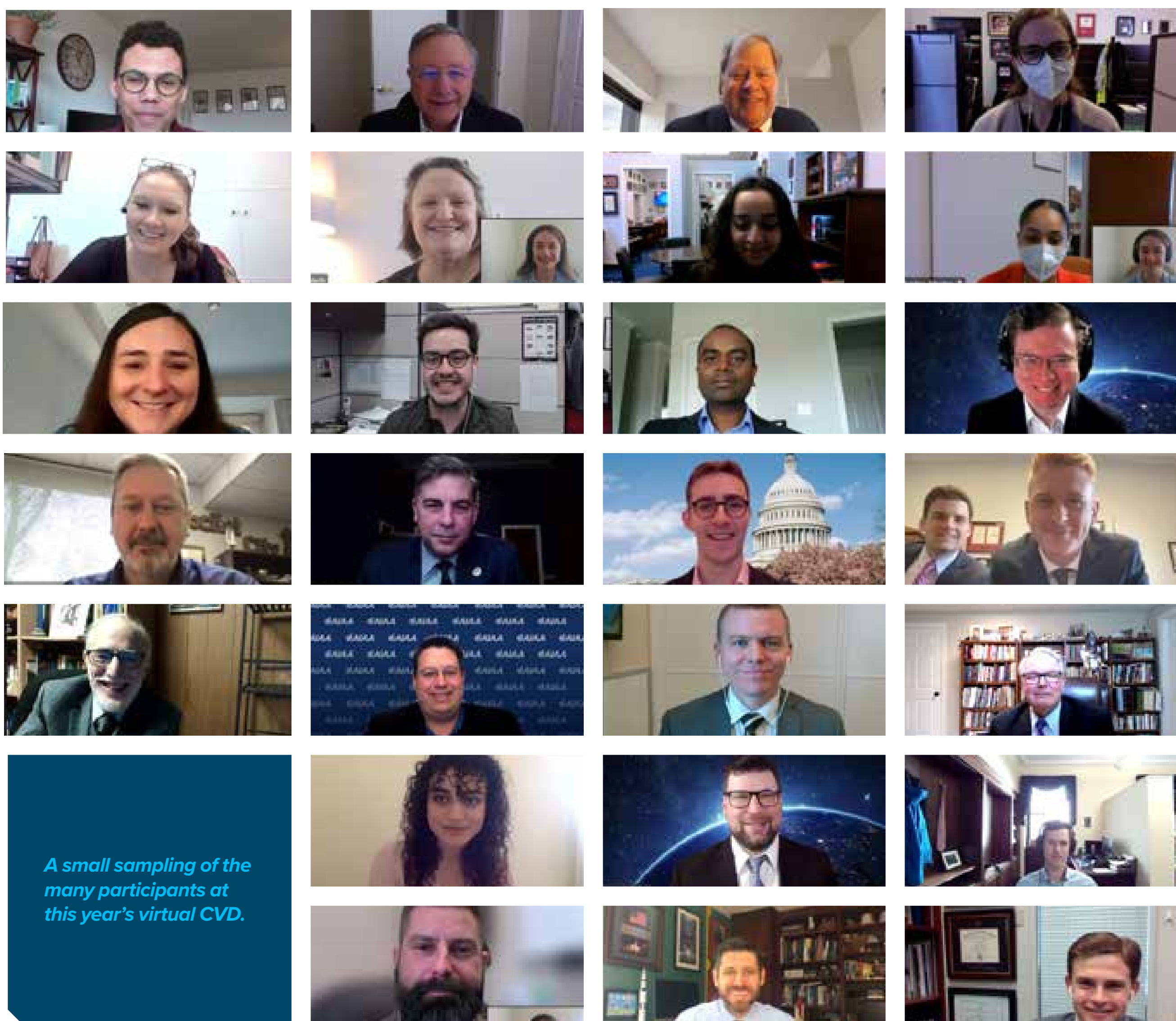
"ICME Optimization of Advanced Composite Components of the Aurora D8 Aircraft"
Michael N. Olaya, Evgenia Plaka, Kalima Bukenya, Sagar Shah, Manish Nagaraj, Marianna Maiaru, University of Massachusetts; Hashim Al Mahmud, University of Kufa, Iraq; Gregory M. Odegard, Prathamesh Desphande, Aaron Krieg, Sagar Patil, Michigan Technological University; Evan J. Pineda, Brett A. Bednarcyk, NASA Glenn Research Center; Richard Li, Jeffrey Chambers, Aurora Flight Sciences; Stephen Jones, Craig Collier, Collier Aerospace

2022 Congressional Visits Day

During our 24th annual Congressional Visits Day (CVD) program, held virtually 14–18 March, AIAA members from across the country met with their congressional delegations to raise awareness of the aerospace community. They promoted AIAA's 2022 key issues and called on Congress to support the people and the companies in the aerospace sector by

- Accelerating the establishment of policies that facilitate the commercialization of space for U.S. technological competitiveness, economic growth, and national security benefits
- Supporting the growth, evolution, and diversification of the 21st-century workforce to fill the job needs in the industry
- Supporting long-term, robust investments in research and technologies that drive innovation and sustainability across the A&D industry
- Supporting initiatives with associated funding for the recovery and advancement of the A&D industry – including workforce, infrastructure, and technology advancements

Through meetings with members of Congress, legislative staff, and other key stakeholders, CVD raises awareness of the long-term value that science, engineering, and technology bring to America. Thanks to all those who participated, and we hope you will join us for CVD 2023.



A small sampling of the many participants at this year's virtual CVD.

AIAA Announces 2022 Election Results

AIAA has announced the results of its recent 2022 Board of Trustees Member-at Large and Chief, Integration and Outreach Activities Division elections. The newly elected AIAA officials will take office on 28 April.

2022 Election Results for Board of Trustees Member-at-Large
Larry D. James, NASA Jet Propulsion Laboratory
Ben Marchionna, Electra.aero
Stephanie D. Wilson, NASA Johnson Space Center

2022 Election Results for Chief, Integration and Outreach Activities Division
Peter Hartwich, The Boeing Company

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 Monday, 25 April 2022, at 1:00 PM, at the Hilton Crystal City at Washington Reagan National Airport, Arlington, VA.

AIAA Council of Directors Meeting

Notice is hereby given that an AIAA Council of Directors Meeting will be held on Tuesday, 26 April 2022, at 1:00 PM, at the Hilton Crystal City at Washington Reagan National Airport, Arlington, VA.

AIAA Board of Trustees Meeting

Notice is hereby given that an AIAA Board of Trustees Meeting will be held on Wednesday, 27 April 2022, at 9:00 AM, at the Hilton Crystal City at Washington Reagan National Airport, Arlington, VA.

Christopher Horton,
AIAA Governance Director

IMPORTANT ANNOUNCEMENT

New Editor-in-Chief Sought for the AIAA Education Series

AIAA is seeking an outstanding candidate to assume the responsibilities of Editor-in-Chief of the AIAA Education Series. The chosen candidate will assume the editorship at an exciting time as AIAA continues to expand its ability to support eBooks and other electronic content, along with publishing a range of titles in traditional print format.

The AIAA Education Series publishes books that are adopted for classroom use in many of the top undergraduate and graduate engineering programs around the world. These important texts are also referred to daily by aeronautics and astronautics professionals who want to expand their knowledge and expertise. Books in the series present the subject material tutorially, discussing fundamental principles and concepts.

A successful series Editor-in-Chief will have a broad range of interests beyond strictly technical aerospace topics, and some familiarity with book publishing is preferred. The editor works closely with AIAA Headquarters staff to identify new topics and potential authors, maintain high-quality print and electronic content, and promote the series and AIAA's publishing program. They will evaluate book proposals and manuscript submissions, recommend outside manuscript reviewers, and work with AIAA staff to ensure that all proposals are processed in a fair and timely manner.

Interested candidates are invited to send letters of application describing their reasons for applying, summarizing their relevant experience and qualifications, and offering initial priorities for the book series; full résumés; and complete lists of publications to:

Michele Dominiak
Managing Director, Publications
Email: micheled@aiaa.org

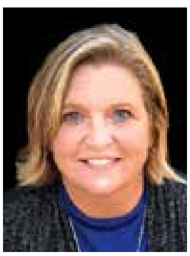
A minimum of two letters of recommendation are required. The recommendations should be sent by the parties writing the letters directly to Ms. Dominiak by email. To receive full consideration, applications and all required materials must be received at AIAA Headquarters by 30 April 2022, but applications will be accepted until the position is filled.

A search committee appointed by the AIAA Publications Committee Chair, Robert Pitz, will seek candidates and review all applications received. The search committee will recommend a qualified candidate to the Publications Committee Chair for final approval. This is an open process, and the final selection will be made only on the basis of the applicants' merits. All candidates will be notified of the final decision.

MAKING AN IMPACT

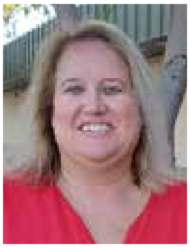
AIAA And Challenger Center Announce Inaugural Winners Of Trailblazing Stem Educator Award

AIAA and Challenger Center have announced the winners of the 2022 Trailblazing STEM Educator Award: Jackie Blumer, Jennifer Cheesman, Kellie Taylor, Cedric Turner, and Katrina Harden Williams. The award celebrates K-12 teachers who go above and beyond to inspire the next generation of explorers and innovators.



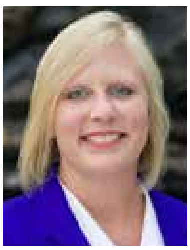
Jackie Blumer, 6th and 7th grade science teacher, Greenville Junior High School, Greenville, IL
For embedding engineering challenges and current aerospace activities into the class curriculum, as well as serving as the AIAA St. Louis Section STEM Chair.

A passionate space science educator, Blumer uses live rocket launches, engineering design challenges, and hands-on programs to excite her students about STEM. She has been at the forefront of the use of digital programs in the classroom, utilizing virtual missions when field trips were no longer an option.



Jennifer Cheesman, 6th grade science teacher, Zuni Hills Elementary School, Sun City, AZ
For exceptional skill in taking high-level concepts and implementing them in fun and engaging ways with inclusive teaching strategies.

Cheesman is dedicated to integrating high-level concepts into engaging and easily understandable methods, including the creation of the “Lab in a Bag” engineering design program, sending engineering kits to students’ homes while they were learning virtually. Prior to being a classroom teacher, Cheesman was a Flight Director at a Challenger Learning Center.

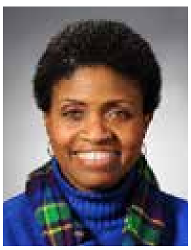


Kellie Taylor, 2nd and 3rd grade teacher, Hawthorne Elementary School, Boise, ID
For sharing a passion for hands-on STEM education with students and colleagues, connecting them to real-world STEM experiences through space education.

Taylor has prioritized STEM in her classroom, focusing on project-based learning with a strong emphasis on coding, robotics, space education, and hands-on programs. She leads STEM curriculum development, hosts STEM-focused after-school activities, and shares her passion for STEM education by leading professional development workshops for her colleagues.

Cedric Turner, high school teacher, Brockton High School, Brockton, MA
For tireless work at Ashfield, South, and North Middle Schools, and Brockton High School, providing inspiration and STEM education to minority and underrepresented students.

Turner focuses on inspiring the next generation of minority and underrepresented students in STEM through his after-school program, “Empower Yourself,” and lunch and learn programs that connect students to local STEM professionals and STEM competitions and educate students about wealth management and economic success.



Katrina Harden Williams, middle school teacher, Ames Middle School, Ames, IA
For enthusiastic pursuit of out-of-this-world K-12 educational experiences, and ingenious connections between real-world STEM topics, classroom education, and students’ imaginations, appealing particularly to underrepresented groups.

Williams is enthusiastic about connecting real-world STEM careers and lessons to the classroom, as well as exposing underserved and underrepresented students to STEM disciplines and careers. During the pandemic, she creatively taught her students about PPE and other COVID support programs. She frequently hosts STEM-focused after-school activities, field trips, and career expos.

Each teacher, and their respective schools, will be awarded $5,000. In addition, the teachers can select from Challenger Center’s suite of hands-on, simulated learning experiences based on their classes’ needs. The educators will be recognized at the AIAA Awards Gala, where one of the five educators will be named the grand prize winner and be invited to join Club for the Future, Blue Origin’s nonprofit, at a future New Shepard launch. The five winners also will be celebrated in their local communities in the coming weeks.

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

A New Year at the University of Adelaide's Student Branch

Mahdy Alhameed, AIAA University of Adelaide Student Branch President

AIAA booth at the University of Adelaide's Orientation Week. Student branch members with branch president Mahdy Alhameed (second from right).

The AIAA University of Adelaide Student Branch recruited new students at the university's Orientation Week in February as they encouraged students interested in aerospace to sign up for a student membership to maximize their university opportunities, connections, and social fun throughout the year. They discussed some of the year's highlights, such as the Design/Build/Fly competition (DBF), tour of the aviation museum, BBQs, and a Yuri's cinema night. With over 50 new members the branch is excited to put teams together to participate in DBF for the first time, participating in a competition that brings theory learnt in class to real-world experience.

AIAA Greater Huntsville Section Aerospace-Themed Valentine's Day Contest

By Tracie Prater

This year AIAA Greater Huntsville Section invited professional members, children of members, and students sponsored by our AIAA Educator Associates to submit aerospace-themed Valentine's Day cards. The section received over 70 submissions in three categories: children under 12, ages 12-18, and adult. All submissions were posted on the section's social media account. Winners were determined based on the number of "likes" at the end of the voting period. First- and second-place winners in each category received gift cards to their choice of sweet shops in Huntsville. We loved seeing all the creative submissions and especially appreciate the great participation from the students of our AIAA Educator Associates. The contest was a fun way to interact with our members.

Our 1st-place entry in the adult category was a clever Skylab-themed Valentine from David Hitt. First place in the 12-18 division went to Sawyer Yarbrough and Jordan Ratton with their baby Yoda-themed Valentine. In the youngest age division, first place went to Evan Chisgah with a cosmic comparison.

Obituaries

AIAA Associate Fellow Watts Died in June 2021

Alfred C. Watts died on 19 June. He was 77 years old.

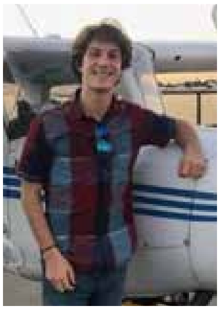
Watts graduated from Mississippi State University with a B.S. in Electrical Engineering in 1966. He joined the Sandia Corporation as a member of the Technical Development Program, earning a Master of Science in Electrical Engineering (M.S.S.E) degree from the University of New Mexico in 1967. He returned to Mississippi State to pursue a Ph.D. in 1970 before rejoining Sandia as a member of the Doctoral Studies Program in 1971. In 1972 Watts received a Ph.D. in Electrical Engineering and continued work at Sandia as a Member of the Technical Staff.

Watts spent his entire professional career at Sandia National Laboratories. He made significant contributions to a variety of flight system applications and the development of the U.S. missile defense system over the years. One of his most notable contributions involved the autopilot control system for a winged maneuvering reentry vehicle that he helped develop in the late 1970s. The initial development effort culminated in a successful flight-test in 1985 and eventually led to another flight test 25 years later using updated control system technology which Watts conceived and implemented. The results of this flight test legacy serve as the foundation for a new hypersonic weapon system that the United States is developing.

His technical interests throughout most of his career focused on inertial navigation and guidance and control systems for missiles and maneuvering reentry vehicles. He was a visionary and an accomplished engineer and missile defense pioneer in the field of hypersonics. Post-retirement, he continued his association with Sandia as a consultant.

His abilities were well known throughout Sandia, and the broader communities throughout the government sector that he worked with on military aerospace technologies and applications. Watts provided a wealth of technical contributions at the project level. He also spent a few years supporting clandestine activities of national security significance during a stint in Sandia's intelligence organization.

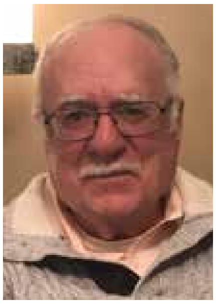
An AIAA Associate Fellow, Watts was a member of the AIAA Guidance, Navigation, and Control Technical Committee for several years.



AIAA Student Member Lewis Died in December 2021

Hunter N. Lewis died 30 December. He was 21 years old.

Lewis grew up in northern California before attending California State University, Long Beach, where he was studying aerospace engineering. His goal was to be an astronaut, and he had had just been accepted into NASA's early astronaut training program. Lewis also had earned his pilot's license. He was the chair of the AIAA California State University, Long Beach Student Branch.



AIAA Associate Fellow Murad Died in January

Aerospace engineer **Paul A. Murad** died on 24 January. He was 78.

Mr. Murad found his passion for airplanes, rockets, space, and technology early in life. He flew gliders as a teen and was a member of the Civil Air Patrol. For fun, he designed, built, and launched metal rockets that he made in his father's machine shop. He graduated as salutatorian from Aviation High School in Queens, New York, in 1960, and then earned a bachelor's degree in mechanical engineering from the Polytechnic Institute of Brooklyn in 1964.

Mr. Murad started his career as an engineer at the NASA Manned Spacecraft Center. He was responsible for performing reentry ablation analysis on the Apollo capsule. He served for two years as a first lieutenant and member of the 82nd Airborne Division stationed in the Dominican Republic and Fort Bragg. He returned to Houston to work at NASA and later earned his master's in aeronautical engineering and astrodynamics at New York University in 1968.

Mr. Murad worked at Aerojet, Martin Marietta, G.E. RESD, and Bendix Corporation from 1968 to 1986. He worked to develop and advance a myriad of advanced propulsion systems. These included the NERVA nuclear rocket engine, the SAM-D, the SPRINT Anti-Ballistic Missile (ABM), the SPRINT, the Pershing II Maneuverable Reentry Vehicle, the Shuttle External Tank, and the ICBM Mk. 500 and PGRV AMaRV reentry vehicles. He also evaluated Russian anti-ship missile technology to understand the vulnerability to the Navy High Energy Laser program.

In 1986, he joined the Defense Intelligence Agency where he focused on advanced foreign technology efforts. He also directly supported the Pentagon on the Iran–Iraq War, the Gulf War, Serbia, and Afghanistan. Even after retiring in 2010, Mr. Murad continued his work trying to solve the hardest problems in physics that exist, and he relished every minute of it.

During his career, he published over 140 technical papers covering subjects such as a pseudo-analytical closed form solution to the Navier-Stokes equations, astrodynamics studies involving Libration points, gravitational models, electrodynamic models such as coining a Murad-Brandenburg Equations which was a Poynting Conservation Law, and the demise of planet Phaeton and its impact upon the solar system cosmology. He also authored nine books about science fiction, genocide, and pulsars. He helped move the world forward while most simply maintained it. Few have the opportunity to live such a rewarding life.

Mr. Murad joined AIAA in 1967 and was an AIAA Associate Fellow, Class of 2011. He was a member of the AIAA Space Settlement Technical Committee, and he attended several AIAA Aerospace Science Meetings and took part in AIAA Congressional Visits Day (2010, 2011, and 2012).

AIAA Associate Fellow Sutton Died in February

Kenneth Sutton died on 7 February. He was 83 years old.

Sutton earned a Bachelor of Science degree and a Master of Science degree, both in Mechanical Engineering, from the University of Florida in Gainesville. He subsequently earned a doctorate in Mechanical Engineering from North Carolina State University, and a Master of Science degree in Government Administration from George Washington University.

In 1962, Sutton joined NASA Langley Research Center. He retired in 2002 as Chief of the Aerothermodynamics Branch after 40 years of dedicated service. His NASA career included numerous achievement awards, including the NASA Exceptional Engineering Achievement Medal, related to his leadership and personal technical contributions in the field of aerothermodynamics for space transportation and planetary entry vehicles. Sutton continued his engineering career as a Senior Research Fellow with the National Institute of Aerospace. He retired in full 10 years later.

Sutton joined AIAA in 1969 and was an Associate Fellow; he was also a member of the American Society of Mechanical Engineers.

AIAA Fellow Del Balzo Died in February

Joseph Del Balzo died on 11 February. He was 85 years old.

Del Balzo earned an engineering degree from Manhattan College in 1958 before beginning as an entry-level engineer with the FAA. He also earned a master's in engineering management from Drexel University in 1967.

Del Balzo served in a number of senior-level roles with the FAA. He was the chief technical advisor for Europe, Africa, and the Middle East, coordinating research and development efforts between the United States and those regions. He led the FAA Technical Center, achieving national and international recognition for its work in the areas of airport and airspace systems analysis, aircraft fire safety, electronic systems testing, and pilot judgment studies.

He later became executive director of system operations, defining requirements for new technology and operation of air traffic control systems. Del Balzo also organized the participation of National Airspace System users, operators, and producers. After holding the role of FAA deputy administrator, from 1992 to 1993 he was acting administrator.

In 1994, Del Balzo founded JDA Aviation Technology Solutions working with a range of international clients on airport and airspace planning, safety, security, training, and technology applications, working with a range of international clients.

An AIAA Fellow, Del Balzo was a former chairman of the Air Traffic Control Association and a former member of the Civil Tilt-Rotor Advisory Committee. He had served on the board of Weather Information Technologies.

CONTINUED FROM PAGE 64

Flash forward, and I'm now focused on solving problems related to space sustainability, including avoiding additional pollution and mitigating the pollution that's already there. There's no shortage of innovative ideas in my field. What's lacking is enough curiosity at a global level to complete the chain from awareness to empathy to compassion and action.

Let's look at empathy. As a creator of knowledge about the orbital environment, one of my mantras is that to know something one must measure it. In a sense, empathy could be viewed as our way of measuring or quantifying a condition experienced by others. It's a necessary step, but just as measurements alone cannot solve a technical problem, empathy alone is also insufficient. We must view empathy as the doorway to motivate compassion.

On the topic of space sustainability, I regularly engage people to help raise awareness. Perhaps I've generated some empathy for the astronauts and cosmonauts whose lives are threatened by debris or for the astronomers whose ability to see clearly into the cosmos is now compromised. My biggest struggle is to get us to turn our empathy to compassion and action. In a sense, we must feel compassion for our future selves in the following sense: The uncoordinated growth of space traffic and pollution could someday make it impossible for any of us to communicate over the internet, to navigate our world, engage in modern commerce or open the space frontier.

With compassion as our goal, here is the process as I see it for those and other problems: First, we must be curious enough to become aware of the pain, struggles and frustrations of others. Curiosity exists when we recognize our own ignorance and become motivated to remove that ignorance. The ensuing learning creates awareness, and ideally this awareness leads to empathy and compassion. Whew, we have a long chain of criteria to meet if we wish to solve societal problems.

There's probably no better way to motivate compassion than by providing evidence to someone that the problems ailing others are, in the end, also our own. The idea that all things are interconnected and the spirit of stewardship can be fertile ground for growing compassion and making it flourish. Humanity, and the Earth as a whole, would be the better for it. ★

LOOKING BACK

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1922

April 7 The first midair collision between two airliners occurs between a French Farman Goliath of Cie de Grand and a British de Havilland DH.18A from Daimler Hire. The collision over Thieuloy-Saint-Antoine in France kills all seven aboard. David Baker, **Flight and Flying: A Chronology**, p. 142.

1 **April 16** The German Republic and Soviet Russia sign the Treaty of Rapallo, which led to increased military cooperation between the two countries. Germany and Russia go on to establish a series of secret bases, the first of which is a flying school for German pilots in Lipetsk, Russia. Later, Germany establishes an aircraft factory in defiance of the Treaty of Versailles that ended the first World War. David Baker, **Flight and Flying: A Chronology**, p. 142.

2 **April 25** A prototype of the Stout ST-1, the first all-metal airplane designed for the U.S. Navy, makes its first flight, piloted by Eddie Stinson. The twin-engine land-based bomber design is not chosen for production because of stability problems. Eugene M. Emme, ed., **Aeronautics and Astronautics 1915-60**, p. 15.

1947

April 4 The International Civil Aviation Organization is founded, with headquarters in Montreal, Canada. R.E.G. Davies, **A History of the World's Airlines**, p. 426.

April 7 U.S. automobile pioneer Henry Ford dies at age 83. Ford financially supported William Stout, who established the Stout Metal Aircraft on Ford's property in Dearborn, Michigan, in 1922. The company later became a division of the Ford Motor Co., and its first product was an all-metal monoplane powered by a single Liberty XII engine. Ford also developed the all-metal Ford Tri-Motor, a 12-passenger high-wing monoplane. **The Aeroplane**, April 18, 1947, p. 385.

April 15 The Douglas D-558-1 Skystreak transonic research aircraft makes its inaugural flight with company pilot Eugene May at the controls. The design is powered by a single Allison J35 turbojet and can reach a top speed of 1,048 kph. Three of the planes are built in the Navy-NACA project. E. Emme, ed., **Aeronautics and Astronautics 1915-60**, p. 56.

April 15 A Lockheed Constellation operated by British Overseas Airways Corp. departs London Airport for Montreal, Britain's first commercial air service between the U.K. and Canada. **The Aeroplane**, April 18, 1947, p. 404.

April 25 N.A.C.A.'s Pilotless Aircraft Research Division at Langley Field at Wallops Island, Virginia, launches its first rocket-propelled model to test the aerodynamics of the U.S. Air Force's Republic XF-91. The experiment initiates N.A.C.A.'s regular practice of conducting flight tests with rocket-propelled models of virtually all Air Force and U.S. Navy supersonic airplanes. E. Emme, ed., **Aeronautics and Astronautics 1915-60**, p. 56.

April 30 The U.S. Army and Navy establish a standardized system of designating guided missiles and assigning them popular names. The basic designations involves a two-letter combination of "A" (air), "S" (surface) and "U" (underwater). A name's first letter indicates the launch origin of the missile, and the second indicates location of its target. The third letter, "M," designates "missile." E. Emme, ed., **Aeronautics and Astronautics 1915-60**, p. 56.

Also in April NASA's predecessor, the National Advisory Committee for Aeronautics, launches the first solid-fuel Deacon sounding rocket from Wallops Island Station. The rocket reaches a velocity of 1,280 meters per second. W. Ley, **Rockets, Missiles, and Space Travel**, p. 313.

Also in April Britain announces its new radio-controlled, surface-to-air Fairey Stooge guided missile, produced by Fairey Aviation. The ramp-launched missile is boosted for 1.6 seconds by four externally mounted 8-centimeter solid-fuel motors with a combined thrust of 5,600 pounds. The boosters are then jettisoned. **The Aeroplane**, April 18, 1947, pp. 383-384.

April 3-20 NASA's Ames Research Center's Convair 990 aircraft flies over a test site in the Beaufort Sea north of Point Barrow, Alaska, as part of the Arctic Ice Dynamics Joint Experiment. This research program conducted by Canada, Japan and the U.S. aims to obtain quantitative data on interactions of pack ice and ocean currents to help solve problems related to Arctic ice cover, its influence on global ocean circulation and ship passage through ice-covered seas. The Convair 990 carries instruments including an infrared imager, infrared radiometers and a laser geodolite, flying above the site in a precise pattern to obtain remotely sensed data to correlate with measurements on the ground. **Astronautics and Aeronautics, 1972**, p. 128.

1972

April 4 The Soviet Union launches a Molniya-1 communications satellite in tandem with France's SRET 1 from the Baikonur Cosmodrome on a single RD-107B booster rocket. This particular Molniya-1 is to provide a remote telephone-telegraph radio-communications system and the transmission of Soviet central television programs to stations of the Orbita network. SRET 1, short for Satellite for Experimental and Technical Research, is designed to study the characteristics of solar batteries for space operations and the degeneration of solar cells from cosmic ray exposure in the Van Allen radiation belts. This is the first of three planned SRET satellites. **Astronautics and Aeronautics, 1972**, p. 128.

April 6 NASA announces plans to land the Viking 1 spacecraft on the surface of Mars on July 4, 1976, to mark the 200th anniversary of the nation's founding. Viking is scheduled to enter Mars orbit around July 1, 1976. **Washington Post**, July 6, 1972, p. A-2.

April 6 NASA and the National Science Teachers Association announce the selection of 25 finalists for the Skylab Student Project. This competition to propose flight experiments and demonstrations to fly aboard NASA's Skylab space station in 1973 received 3,409 from U.S. high school students and students from nine schools outside the U.S. **NASA Press Release** 72-71.

April 7 The Soviet Union launches Intercosmos 6 from the Baikonur Cosmodrome. The satellite will study primary radiation, the chemical composition and energy spectrum of space beams in the high-energy sphere, and meteoric particles in inner space. The 1,044-kg science package consists of experiments from the Soviet Union, Czechoslovakia, Hungary, Mongolia, Poland and Romania. **Astronautics and Aeronautics**, 1972, p. 132.

3 **April 16-27** A Saturn V lifts off from NASA's Kennedy Space Center with the three-astronaut crew of Apollo 16, NASA's fifth lunar landing. The Orion lunar module carrying astronauts John W. Young (commander), Thomas K. Mattingly II (command module pilot) and Charles M. Duke Jr. (lunar module pilot) lands in the moon's Descartes region, where Young and Duke conduct lunar surface experiments and ride a Lunar Roving Vehicle. After 71 hours and 14 minutes on the lunar surface, the longest of any Apollo mission, Orion rejoins the Casper command and service module. The astronauts

return to Earth with 96.6 kg of lunar samples, the largest amount brought back to date. **New York Times**, April 16-30, 1972.

April 23 A NASA's Ames Research Center researcher announces the possible discovery of the historical point of the origin of life. Organic geochemist Keith A. Kvenvolden's analysis of 3.4-billion-year-old rocks retrieved from the Barberton Mountain Land near South Africa's border with Swaziland shows fossil evidence of carbon produced by early photosynthetic organisms. **Washington News,** April 25, 1972, p. 10.

April 25 West German pilot Hans-Werner Grosse sets a new world record in long distance straight line glider flying with a 1,450-kilometer flight from Lübeck Airport in West Germany to Biarritz, France. His 12-hour flight in an ASW 12 all-plastic glider is 274 kilometers longer than the previous record set by U.S. pilot Wallace Scott. **New York Times**, May 28, 1972, p. 42.

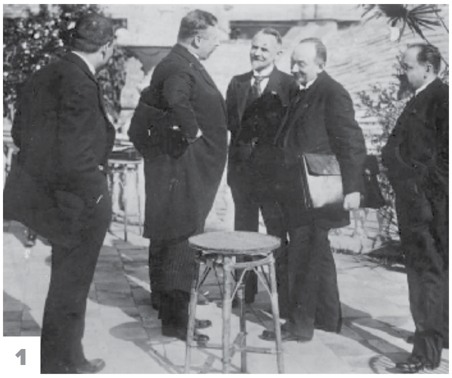
4 **April 26** The Lockheed L-1011 TriStar widebody jet flies its first passengers on an Eastern Air Lines flight between Miami and New York via Atlanta. The TriStar is the third widebody airliner to enter commercial operations. **New York Times**, April 27, 1972, p. 85.

1997

5 **April 1** Princeton University announces the death of former Princeton Observatory director Lyman Spitzer Jr., the astrophysicist who long advocated for large orbiting space telescopes. The namesake for NASA's infrared Spitzer Space Telescope, he was the principal scientific investigator of the Copernicus satellite, launched in 1972. **Aviation Week**, April 7, 1997, p. 29.

6 **April 4** The space shuttle Columbia launches from Cape Canaveral on flight STS-83 commanded by James D. Halsell and piloted by Susan L. Still. The 22nd mission of Columbia, STS-83 carries the Microgravity Science Laboratory as well as other experiment packages for long-duration missions in preparation for the upcoming International Space Station. **NASA, Astronautics and Aeronautics: A Chronology, 1996-2000**, p. 65.

April 21 Orbital Sciences' air-launched Pegasus XL rocket takes off from the Canary Islands and boosts Spain's first science satellite, MiniSat, to orbit. The rocket's third stage carries a small capsule with the cremated remains of 22 people, including "Star Trek" creator Gene Roddenberry and rocket pioneer Krafft Ehricke. The capsule will orbit Earth for three to five years attached to the stage before burning up in the atmosphere. **Aviation Week**, April 28, 1997, p. 67.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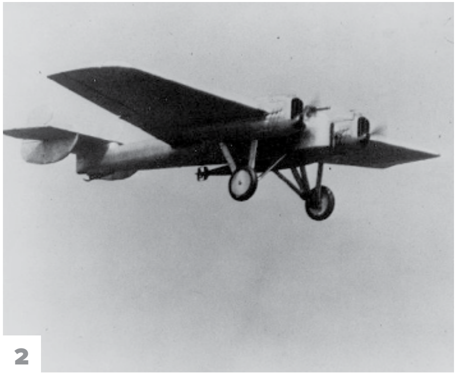
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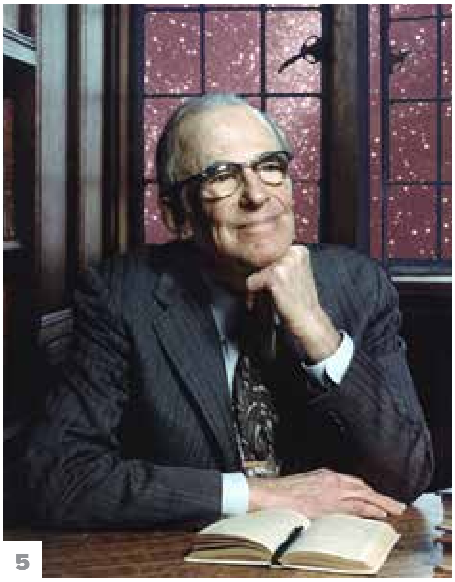
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Knowledge and empathy alone can't inspire action

BY MORIBA JAH | moriba@utexas.edu

We have a war in Ukraine, monumental crises related to climate change and environmental unsustainability on Earth and in space, a growing disparity between the wealthy and the poor, and a plague of misinformation in the United States and abroad. Our modern lives and humanity's very existence have reached an inflection point. We need holistic solutions to these and other societal problems, and we need fresh ideas about how to create them.

One might think that our biggest obstacle is a shortage of innovative policy or technical solutions, but in reality, the largest impediment is a lack of compassion for those suffering the brunt of these crises. Even when we have empathy for people who are bombed and under siege or suffering in a climate-induced drought or forced to take refuge in orbit from space junk, we can have a tendency to file such crises under "not my problem." We count ourselves lucky and perhaps make a donation when we should realize that these problems are ours too.

Let's look at the concept of compassion. When I worked at NASA's Jet Propulsion Laboratory as a spacecraft navigator, I developed a method to navigate aerobraking spacecraft autonomously. I was even formally recognized with a NASA Space Act Award for my method. Autonomy wasn't implemented, not because the idea sucked but because there wasn't wide acceptance that the problem I aimed to solve — labor-intensive operations — was really a problem at all. JPL has been quite successful at getting humanmade hardware across the solar system with conventional navigation. Because no one else was particularly frustrated by the problem I saw, no one felt compassion for it and therefore no action was taken.

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