AEROSPACE AMERICA

The comet question

Are we giving these cosmic transients the attention they deserve in planetary defense?

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The European Space Agency's Giotto probe took this photo in 1986 as it passed within 600 kilometers of Halley's Comet, the first close-up images of a comet nucleus. During each of its 76-year orbits around the sun, Halley sheds between 1 and 3 meters of the rocks, dust and frozen gases that comprise its nucleus, according to NASA. The comet is projected to next be visible from Earth in 2061.

Halley Multicolor Camera Team, Giotto Project, ESA

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SHAPING THE FUTURE OF AEROSPACE

IN THIS ISSUE

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. PAGE 64

Aaron Karp

Aaron has covered the aviation business for 20 years, including as managing editor of Air Cargo World and editor-in-chief of Aviation Daily. He remains a contributing editor to the Aviation Week Network. PAGE 36

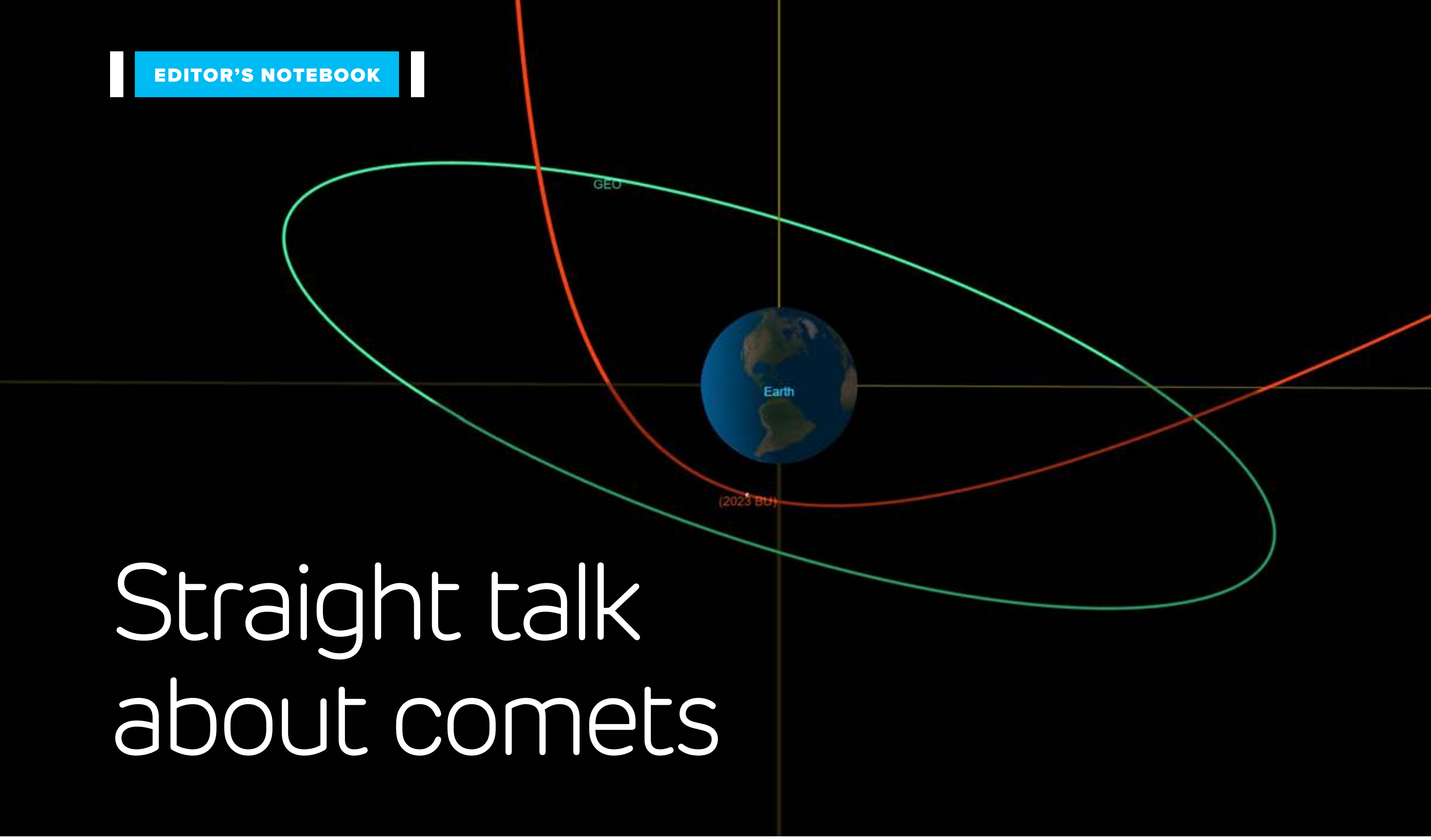
Karen Kwon

Karen is a science journalist based in the Washington, D.C., area, currently working as the associate editor of Optics & Photonics News. She holds a doctorate in chemistry from Columbia University and previously wrote about physics, space science and technology for Scientific American. PAGE 18

Jon Kelvey

Jon previously covered space for The Independent in the U.K. His work has appeared in Air and Space Magazine, Slate, Smithsonian and the Washington Post. PAGE 24

DEPARTMENTS



Straight talk about comets

Ten years ago, news broke that an asteroid packing 180 times the explosive power of the Hiroshima bomb would pass startling close to Earth, inside the geosynchronous satellite ring, in fact. On the day that Asteroid 2012 DA14 flew by us, the internet and cable TV lit up with accounts of an explosion and streaks of light over the city of Chelyabinsk, Russia, followed by reports of a powerful shockwave that ended up injuring 1,600 people, mostly with broken glass.

Non-experts like myself initially assumed that the Chelyabinsk meteor was related to 2012 DA14. NASA right away dispelled this idea: The Chelyabinsk debris traveled north to south, and DA14's trajectory was in the opposite direction. It was all a coincidence.

Our cover story about comets brought this memory to the fore. I don't know what the odds were that a dangerous strike and an entirely separate brush with devastation would occur on the same day, but they must have been infinitesimal. And yet it happened.

Rare occurrences like this spring to mind whenever I hear someone say that a comet impact with Earth is an extremely remote possibility, and this is why so much more emphasis is placed on being ready to defend against a wayward asteroid. I also wonder whether the people on Jupiter (lol) dismissed comets only to have Comet Shoemaker Levy-9 break up and slam into them. Or whether the person who won the $1.35 billion lottery in Maine last month really thought there was a chance. Or about the time I was on a Metro train in Washington, D.C., with a new colleague, and we discovered that we grew up in the same New England town, a few houses away but 15 years apart, and he was friends with my future high school coaches, and what an amazing coincidence it all was. And then a young woman in the seat ahead turned and asked if we were talking about Nashoba Regional High School, and our collective minds were blown.

You see my point. Unlikely things happen. I'm glad that, as our cover story describes, some experts in planetary defense are thinking about reasonable things that could be done to be ready in the event a new light appears in the night sky — and it will not pass by us like Comet Hale-Bopp did in 1997.★

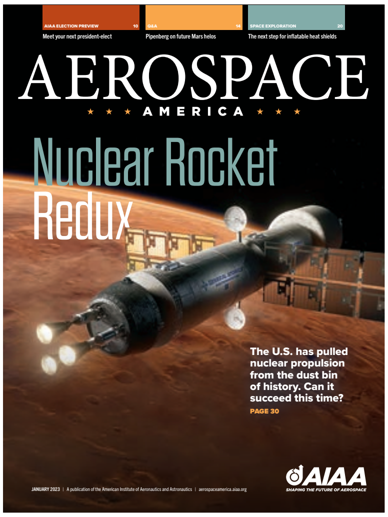
▲ On Jan. 26, the asteroid 2023 BU passed 3,600 kilometers above Earth's surface, just five days after it was discovered by an amateur astronomer. NASA said there was no risk of a collision because BU is small enough that it would disintegrate in the atmosphere. In this diagram, the red ring represents BU's orbit and the green ring represents the geosynchronous satellites surrounding Earth.

NASA/JPL-Caltech

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

On page 39 of the December issue, we listed incorrect dimensions for the Pathfinder 3 airship in development by Lighter than Air Research. It is 185 meters long.

On page 40, we gave the incorrect destination and distance for Beta Technologies' May 2022 flight. The aircraft flew 3,028 kilometers on the roundtrip from Plattsburgh, New York, to Bentonville, Arkansas.



In our January cover story, we gave the incorrect year for when DARPA planned to conduct the on-orbit demonstration with its nuclear thermal rocket. At the time of the story, it was fiscal 2026.

Membership Honors Serve to Inspire the Next Generation

AIAA is dedicated to supporting the growth, evolution, and diversification of the 21st-century workforce to fill the job needs in the industry. This topic has been one of our Key Issues for the last several years because of its vital importance. Current statistics show that there were approximately 3.6M high school students in the United States in 2021; in the same year 144,000 students graduated with engineering bachelor degrees in the United States. The Institute believes that offering inspirational and experiential STEM education programs to students and educators at the K-12 levels is necessary to meet the aerospace workforce demands of the future. AIAA provides scholarships, awards, and design competitions to university undergraduate and graduate students to continue supporting our student members' classroom-to-career journey. We also offer membership advancement as a distinguished honor and valuable element of workforce development.

AIAA advancement recognizes career contributions to the aerospace community and is open to all aerospace professionals. The distinction members gain with each membership advancement earns the respect of peers and employers and bolsters a member's reputation throughout the community. For our young professionals and students, this recognition is key to accelerate and "ignite the future!"

The first level of distinction is **Senior Member**, for individuals who have demonstrated a successful professional practice in the arts, sciences, or technology of aeronautics or astronautics for the equivalent of at least eight years.

The next level is **Associate Fellow**, acknowledging individuals who have accomplished or been in charge of important engineering or scientific work, or have done original work of outstanding merit, or have otherwise made outstanding contributions to the arts, sciences, or technology of aeronautics or astronautics. The Institute currently has over 3,300 active Associate Fellows.

The next level is **Fellow**, celebrating individuals of distinction in aeronautics or astronautics who have made notable valuable contributions to the arts, sciences, or technology of aeronautics or astronautics. 2,038 distinguished persons have been elected to the rank of AIAA Fellow.

The highest membership honor is **Honorary Fellow**, commending individuals of eminence in aeronautics or astronautics distinguished by long and highly contributive careers. In 1933, Orville Wright became AIAA's first Honorary Fellow, and there have been 238 elected since.

The accomplishments of AIAA members at these levels serve as a source of inspiration and example for our young professional members and student members. They can see and personalize the possible futures ahead of them in their careers and aspire to even greater heights. This virtuous cycle will surely help the Institute continue developing our workforce. Celebrating the best and brightest minds in our community encourages us all as we work together shaping the future of aerospace. ★

Dan Dumbacher
Executive Director, AIAA

Nominations for the Class of 2024 Associate Fellows open in February. Nominations for the Class of 2024 Honorary Fellows open in February; nominations for the Class of 2024 Fellows open on 1 April. Look around your network, your local section, or your committee, and nominate a colleague you believe deserves this AIAA honor. Find the specific criteria and forms at **aiaa.org/honorsandawards**.

During the 2023 AIAA SciTech Forum in January, the Institute honored the newly elected Class of 2023 Associate Fellows. We look forward to honoring the Class of 2023 Fellows and Honorary Fellows at the AIAA Awards Gala in May. Every year, it is a privilege to celebrate each new class of distinguished members.

AERO PUZZLER

Email us at aeropuzzler@aerospaceamerica.org

Erasing gravity

Q: You have developed an anti-gravity machine that isolates itself and the occupant from the effects of gravity. You take it to the equator for testing, climb in and turn it on. What happens then and why? Suppose you take it to the North or South Pole for testing — how would the results be different there?

This question was submitted by Steve Justice of IGNITEQ LLC, who will review your responses.

SEND A RESPONSE OF UP TO 250 WORDS that someone in any field could understand to aeropuzzler@aerospaceamerica.org by noon Eastern Feb. 15 for a chance to have it published in the next issue.

Scan this QR code to get a head start on the March AeroPuzzler

NAPOLEON IN SUNGLASSES: We asked you to identify the French physicist our time-traveling fantasy novel protagonist visited to give Napoleon sunglasses over 100 years before Edwin Land invented them.

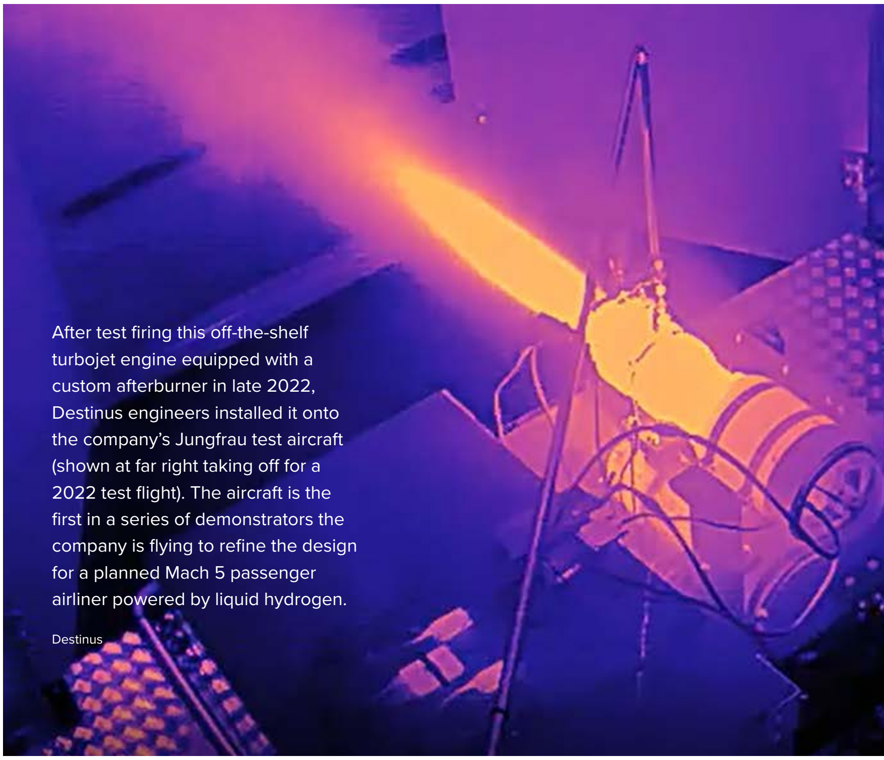
WINNER Light sources like the sun produce electromagnetic light waves, which are oriented in many random directions (unpolarized light). The polarization of these light waves allows them to oscillate only in one direction. Components that polarize light or split or suppress polarized light, depending on the type and direction of polarization, are called polarizers. This effect was first discovered by the French physicist Étienne-Louis Malus.

Malus took part in Napoleon Bonaparte's Egyptian expedition from 1798 to 1801, and in 1808 began experiments on the refraction of light sources and the systematic investigation of the properties of surfaces with regard to reflection and refraction. In 1809, he discovered that light is partially linearly polarized when it is reflected, i.e., that polarized light waves only oscillate in one plane. The dependence of the intensity of the polarized light on the alignment of a polarizing filter (analyzer) held in front of it is referred to as Malus' law.

In 1936, Edwin H. Land invented polarized lenses, the birth of the "Malus sunglasses." More than 125 years earlier, Napoleon had to face his dark end without this wonderful invention. Polarizing sunglasses only allow light waves in one direction through, thereby reducing the intensity of light entering the eye. Reflecting surfaces such as water and glass also polarize light to a certain extent, thereby rendering polarizing sunglasses even more effective.

Peter Hamel, AIAA Fellow
Braunschweig, Germany

Peter led the Institute of Flight Systems at the German Aerospace Center, DLR, from 1971 to 2001.



After test firing this off-the-shelf turbojet engine equipped with a custom afterburner in late 2022, Destinus engineers installed it onto the company's Jungfrau test aircraft (shown at far right taking off for a 2022 test flight). The aircraft is the first in a series of demonstrators the company is flying to refine the design for a planned Mach 5 passenger airliner powered by liquid hydrogen.

Destinus

Testing their way toward hydrogen-powered hypersonic flight

BY CAT HOFACKER | catherineh@aiaa.org

Combine the cleanliness of hydrogen combustion with the desire to travel at speeds of at least five times the speed of sound, and you've got Destinus, the Swiss startup that wants to build Mach 5 airliners and sell them to airlines to begin passenger service in the 2030s.

"I really see these two parts — sustainability and going fast — as something that we need to combine in order for our company to bring a true value to the aviation industry," says Martina Lofqvist, head of business development at Destinus.

Later this month, the company plans to fly a hydrogen-powered aircraft for the first time when the unoccupied subscale test aircraft Jungfrau takes off from an airport near Munich, with a crew monitoring it from the ground. During previous test flights, Jungfrau was propelled by a conventional turbojet, but this time, its engine will mix compressed air with kerosene for combustion, and once airborne receive an additional burst of thrust through an afterburner that injects gaseous hydrogen into the nozzle jet stream.

This modified turbojet is one of two designs that Destinus is considering pairing with a ramjet for the passenger airliner. The other is a hydrogen-powered "air turbo rocket" engine. In both configurations, the ramjet would burn liquid hydrogen with oxygen supplied by compressing incoming air to accelerate the aircraft to Mach 5.

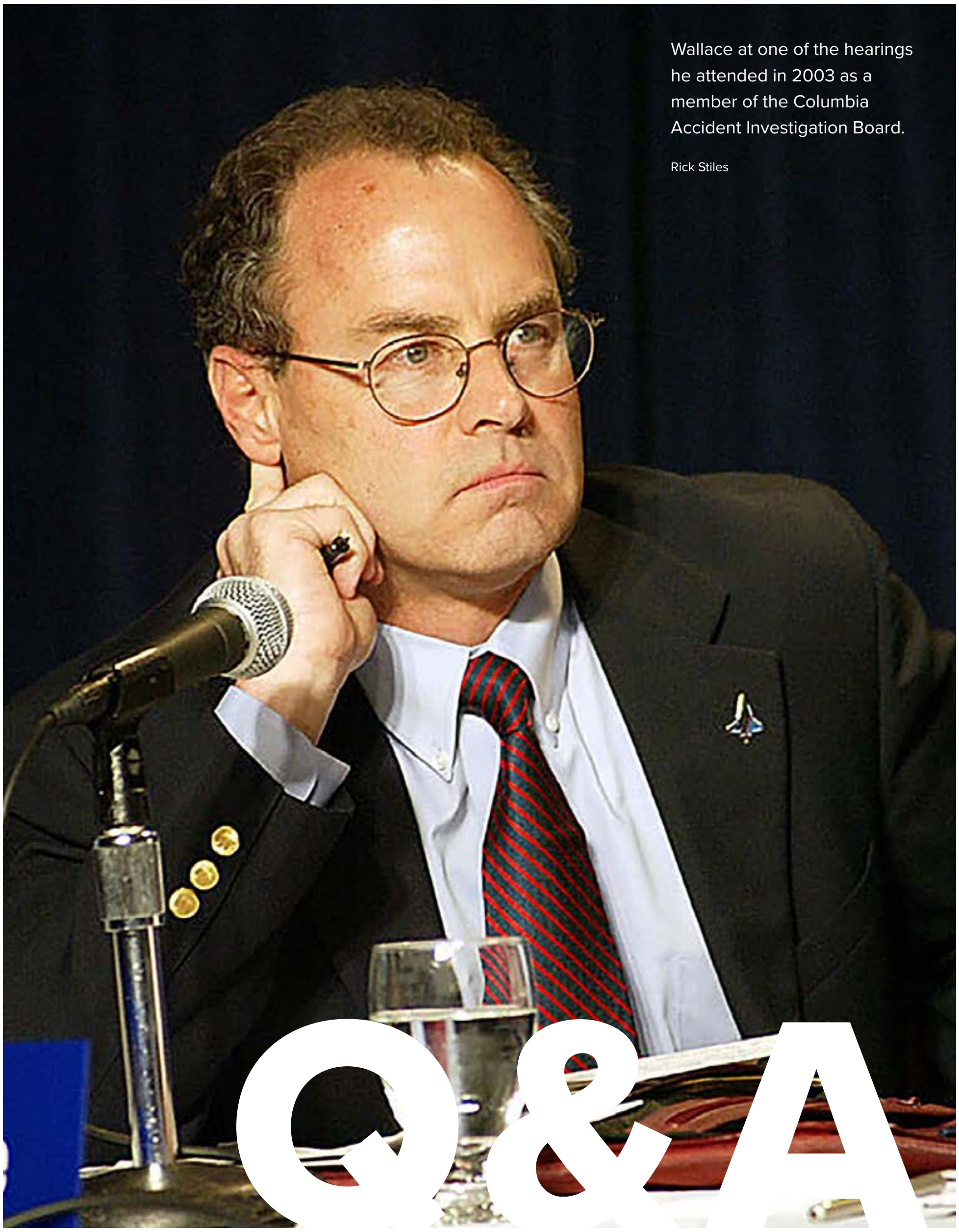
"We really see ourselves as a flight testing company and developing a lot of experience by actually putting stuff in the air," says Lofqvist.

In the February flight, Jungfrau is supposed to fly for about five minutes at about 300 kilometers per hour, Mach 0.2, to prove that its afterburner works as intended. Destinus is confident it will, based on results from a series of ground tests conducted late last year. The company installed the afterburner onto the off-the-shelf turbojet, then hooked the engine up to multiple external fuel tanks, some containing kerosene and others containing gaseous hydrogen. The engine was fired 20 times, with the afterburner operating for a handful of seconds.

The first supersonic test flights are targeted for late 2023, and would be conducted with a larger demonstrator that Destinus plans to reveal later this year. Due to the ban on commercial supersonic flights over land, plans call for flying this aircraft from an airport near the coasts of France or Spain.

Lofqvist says Destinus hopes the ban will eventually be overturned, but it's not counting on it. Instead, the company is planning for its passenger airliners to fly subsonic over land, then accelerate to Mach 5 once over the ocean.

"If we get the approvals to fly with the sonic boom over land, that's great for us," she says. "But then we already have closed the [business] case in case we don't get those approvals." ★



Wallace at one of the hearings he attended in 2003 as a member of the Columbia Accident Investigation Board.

Rick Stiles

Lessons from Columbia

Steven Wallace, like many in the safety of flight business, remembers exactly where he was when he heard that the space shuttle Columbia broke apart 20,000 feet over Texas, killing the seven aboard: It was Saturday and his birthday, so he was playing tennis. Over the next seven months, Wallace would help determine the cause of the tragedy as a member of the 13-person Columbia Accident Investigation Board appointed by NASA. In its 248-page report, the CAIB (pronounced "cabe") concluded that the orbiter was ripped apart when hot atmospheric gases penetrated a hole in the left wing, created by foam that fell from the external tank during launch. The CAIB determined that NASA's culture had also contributed to Columbia's demise by pushing ahead with a rigorous launch schedule to complete initial construction of the International Space Station and dismissing frequent foam strikes as "an acceptable risk." As the 20th anniversary of Columbia approached, I reached Wallace via Zoom to discuss the report's creation and whether its findings still ring true for NASA as it attempts to return humans to the moon under the Artemis program. — *Cat Hofacker*

STEVEN WALLACE

POSITIONS: Since 2008, an aviation consultant specializing in product safety reviews for companies; 2000-2008, director of FAA's Office of Accident Investigation that assists the U.S. National Transportation Safety Board; February 2003-August 2003, member of the Columbia Accident Investigation Board, CAIB, that made a series of recommendations to NASA. These were divided into actions to be completed before the space shuttles resumed flying and long-term changes the agency should make; 1991-2000, FAA senior representative at the U.S. embassy in Rome, where he was the liaison to 20-plus European countries in matters including accident investigations involving U.S. aircraft; 1984-1991, manager of FAA transport standards staff in the Seattle regional office, overseeing engineers, pilots and technical writers who developed certification requirements for transport category aircraft; 1976-1984, legal adviser to FAA's New York and Seattle regional offices.

NOTABLE: Wrote the executive summary of the CAIB report and oversaw the part of the investigation that probed NASA's decision not to further analyze the suspected foam damage to the orbiter. Dual citizen of the U.S. and Ireland. Has a commercial pilot license and has flown a variety of planes. He owns a Sling TSi, a four-seat South African aircraft he built from a kit.

AGE: 74 on Feb. 1

RESIDES: Vashon, Washington, near Seattle

EDUCATION: Bachelor of Science in psychology, Springfield College in Massachusetts, 1971; juris doctorate, St. John's University School of Law in New York, 1975.

Q: Where were you on Feb. 1, 2003?

A: I was playing tennis at an indoor tennis club in McLean [Virginia], where I played several times a week, and I got a phone call from my wife telling me that they lost communication with the space shuttle Columbia. Well, if you lose communication with it, it's because it's gone, except for temporary interruptions. We later learned that in mission control in Houston, a flight controller had told Leroy Cain, who was the asset and entry flight director in charge of the flight at that point, that they were starting to see a few things that looked wrong. Just a very few, and [controllers] did not realize this shuttle had crashed until it was shown on television, and then they saw the three streaks of the main engines going across the sky. The TV people couldn't figure out what it was. This is just over Dallas. Once I got the call, I talked to the FAA administrator and the head of safety for the FAA, who I directly reported to. They did not know that I was predesignated on a NASA plan, because the director of accident investigation was on NASA's contingency plan.

Wallace means that, in his role as director of FAA's Office of Accident Investigation, he was predesignated to serve on the International Space Station and Space Shuttle Mishap Interagency Investigations Board, the group of high-ranking officials who, in the event of a shuttle crash or similar "serious mishaps," would convene. Renamed the CAIB, this board chaired by retired U.S. Navy Adm. Hal Gehman originally consisted of officials from the Defense Department, Department of Transportation and NASA. Gehman later requested that NASA Administrator Sean O'Keefe appoint five additional members who were not government employees, including former astronaut Sally Ride. — CH

So I explained to them that I had this role but I didn't know what was going to happen. Fred Gregory [the deputy administrator of NASA] called me that day or the next day and told me to get on a plane. We made a few stops to pick up a few other CAIB members, including Adm. Gehman. We went initially down to Barksdale Air Force Base [in Louisiana]. That's where they were collecting the debris, but we then quickly moved to Houston.

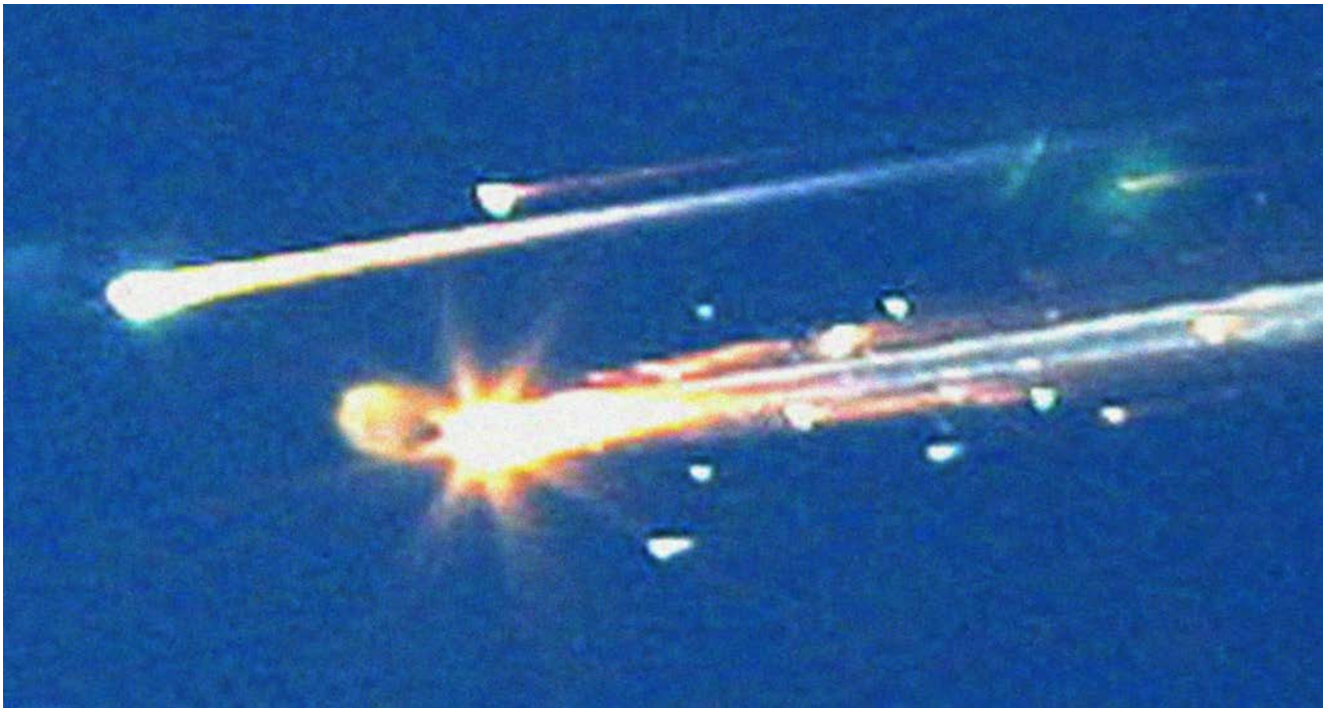
> "NTSB people have a saying that when you find the human error, that's not the end of the investigation; that's the beginning of the investigation."

Q: Did the CAIB realize at that point that your investigation might have to go beyond the physical cause of the accident and examine NASA's culture, as the Rogers Commission did?

A: Not at that point. On the plane ride, Adm. Gehman was sort of drawing us out about our approach — things like are witnesses going to have confidentiality. We can do that, and the military does that [in its investigations], and the civilians don't do that. But what you're describing is very much the key part of the direction of the investigation, and Gehman really took the lead on that. NTSB [U.S. National Transportation Safety Board] people have a saying that when you find the human error, that's not the end of the investigation; that's the beginning of the investigation. What is the true root cause? The root cause is the thing that you have to change so it doesn't happen again. Gehman was very much thinking in those terms, I think, from day one.

Q: In the early days of the investigation where the CAIB was gathering information, how did you decide which member would oversee which part of the investigation?

A: We did that fairly quickly. We broke into four or five groups, and mine was the on-orbit group and the decision making that was done around that. One key aspect of that was the Linda Ham interview, which was done primarily by an investigator that I brought in from FAA.



This photograph of debris from the Columbia orbiter was taken by a cardiologist in Tyler, Texas. The orbiter began disintegrating as it flew across the southern United States, shedding thousands of pieces of debris that would later be collected by NASA, the U.S. Forest Service and volunteers.

AP Photo/Dr. Scott Lieberman

NASA's Linda Ham led the mission management team for the Columbia flight, the group of managers from various parts of the shuttle program whole role was to resolve any problems that arose before or after a launch. — CH

I brought in three people from the FAA and a couple from NTSB to just help my team, and the FAA guys did a very good job in drilling down to that story about how Linda Ham and other managers really suppressed open communications.

Wallace is referring to NASA's handling of requests by engineers to obtain U.S. spy satellite imagery of Columbia on orbit to see if pieces of insulating foam seen striking the orbiter's left wing in launch footage had damaged the wing and, if so, how severely. According to the CAIB, Ham told colleagues she couldn't identify who made the request, so she told the Defense Department liaison that "I don't think we need to pursue this." In a NASA press conference held shortly before release of the CAIB report, Ham at times fought back tears and said: "We were all trying to do the right thing. All along, we were basing our decisions on the best information that we had at the time," according to media reports. — CH

The CAIB members in my group were Sally Ride and Maj. Gen. Kenneth Hess of the Air Force Safety Center. The entire CAIB met every morning. If Gehman wasn't there, I usually ran the meetings, and we'd just have a collegial discussion, but there are often 100 people in the room including the support staff. I will tell you briefly that the NTSB did not agree to be part of the NASA contingency plan. I have a huge respect for that agency, but they really run investigations and are not normally in a good position to participate in investigations that they are not in charge of, because being independent from other agencies is hugely important to them. And so they don't want to put their signature on something that isn't theirs. So they came to the investigation, a lot of them, including the most senior aviation people, but they weren't on the board, and they were so cautious about what they would do and what they would say. But some of them did working-level stuff. One NTSB staffer, he actually laid out the wreckage in the hangar [at NASA's Kennedy Space Center] and his name is Clint Crookshanks. They knew how to do that, and he led that extremely well.

Q: It's very sobering that in addition to the physical cause of the foam, the report concludes that the root cause was NASA's "normalization of deviance" about the frequency of the foam strikes. The CAIB traces that at least in part to how the shuttle fit into the overall U.S. space program.

A: Exactly. That's where I would have started this discussion. You know my birthday; I was 8 when Sputnik went up in 1957. That was the heart of the Cold War. We had drills in my grade school. I came home with literature

> "The best rocket scientists in the world, and NASA lost two shuttles in 135 flights. If you lost 1 in 67 commercial [airline] flights in the U.S., that'd be the end of that industry."

about how to build a bomb shelter, and as a child, I was afraid of that. It was a few years later when President Kennedy said we're going to put a man on the moon in a decade. Well, that was a vision and a very bold vision, and when we started the very first space shots — I was probably in seventh grade when Alan Shephard just went up and back, like these space tourists are doing now — everything in school would stop. We didn't have television coverage. We'd be listening on the PA system. It was a huge deal.

Q: And when the Nixon administration canceled Apollo and gave the go-ahead to develop the shuttle, the U.S. lost that big vision?

A: Right. So where are we now? Well, we have this Artemis mission. We say we're going back to the moon. What has changed is that they didn't know that there was all this water on the moon, and now they know there's water. So now they want to go see if we can establish a permanent presence there, and maybe survive long term or turn water into hydrogen and oxygen. I'm still not clear what the nation's appetite for human spaceflight is. I don't know that people are that interested in it. There isn't that Cold War urgency about it. And are we really going to be putting lives at risk? Spaceflight is very dangerous, and for what long-term purpose, I don't know. They talk about the moon being a potential stepping stone to Mars. I'm not arguing with that, but I'm not sure how much risk the nation is willing to accept.

Q: There is a line in the report about how NASA was an agency "straining to do too much with too little" budget. Is that still true today?

A: I don't have enough intimate knowledge of what the projected costs are and what the budget is. I would

▲ As search and recovery teams located debris from the space shuttle Columbia in East Texas and elsewhere in the southern United States, the pieces were shipped to a hangar at NASA's Kennedy Space Center in Florida for sorting. When this photo was taken in May 2003, some 82,000 pieces of debris had been located, with 753 of them identified as being part of the left wing.

NASA

▲ This picture of the STS-107 crew posing for the traditional in-flight portrait was on a roll of unprocessed film recovered from the orbiter debris.

NASA

just leave it with the fact that I'm not sure that the country as a whole has passion to get to the moon like what they did [in the Apollo years]. I do want to make one point about the risks of spaceflight, given that people are talking about tourism. I love the fact that this country allows people to take risks, and we are at some level an exploring species. But the space shuttle flew 135 times, and they lost two — one going up and one going down. In both cases, compared to these up and down flights conducted by Blue Origin and Virgin Galactic, you have to get going at 17,000 miles an hour to get into orbit. Now you've got this kinetic energy, and you absorb it in reentry. The best rocket scientists in the world, and NASA lost two shuttles in 135 flights. If you lost 1 in 67 commercial [airline] flights in the U.S., that'd be the end of that industry. Now, I think today's commercial spacecraft are much safer, because the space shuttle was inherently complicated and dangerous — self-stabilizing capsules like SpaceX's Dragon are way simpler, way safer. But again, it's hugely risky. The laws of physics just make it that way. And so you have to say, "Why are we going into the orbit?"

Q: That comparison to the airline industry is frequently made, but as you say, spaceflight is inherently risky in a way few other activities are. Is it unfair to expect airline-level safety?

A: Perhaps. The space shuttle was designed and kind of built to be all things to all people. Substantial effort was made to make it look like an airplane and land like an airplane, which it did, and it had all these capabilities. It could go into a polar orbit from Vandenberg Air Force Base [in California, now named Vandenberg Space Force Base], which they never once did, and grab a spy satellite. And then it had to have a large cross-range capability when it came back [to land]. But again, that capability was never used. And like an airplane, it carried the cargo and the crew in the same vessel. You will not see that anymore [in today's capsules]. There's no reason you'd want it. It's safer and easier to separate.

Q: The physical causes of the Challenger and Columbia tragedies are different, but both were linked to the schedule and budget pressure NASA was feeling, which the CAIB report laid out in great detail. What did it feel like when the board pieced that together?

A: The physical cause was pretty clear. The organizational stuff is more subtle, and it's something where you don't typically have a revelation. You just get an increasing sense of things like schedule pressure. But some of the stuff was not so subtle, like Linda Ham asking, "We can say there's not a safety of flight issue, right?" about the foam shedding. Managers suppressed these discussions. That became very apparent.

Wallace is referring, in part, to discussions during mission management team meetings that were recorded, transcribed and reviewed by the CAIB. In one meeting in which the foam strike to the wing was discussed, Ham said NASA "doesn't believe" that the foam penetrated the lower layers of the thermal protection tile, based on an analysis with Boeing software. Therefore, there was "no safety of flight kind of issue, it's more of a turnaround issue similar to what we've had on other flights." In its report, the CAIB alleged that pressure to maintain the schedule of the next schedule launch prompted managers to cut short these discussions." In a NASA press conference shortly before the CAIB report was issued, a sometimes tearful Ham said she "takes responsibility" and "none of us felt that the analysis was faulty," according to media reports. — CH

And they suppressed requests for the military to image Columbia on orbit. I remember I had to go get my top-secret clearance jacked up another level — to what's called sensitive compartmented information — to be able to know the resolution, capability of the spy satellites, and in fact, I don't think I ever actually learned what it was, but I didn't really need to. But if they had seen a substantial hole in the leading edge of the orbiter, they would have immediately known they could not reenter. We did the actual test, firing a projectile at some RCC [reinforced carbon carbon] tiles, and you could put your head through the hole that was made. And so the Columbia board looked at, "Could you have gotten another space shuttle up there?" And the answer was you might have been able

to keep them on orbit for a month, and you might have been able to get another orbiter up there to recover the crew. The other thing we looked at was, "Could the crew of the Columbia have gone out and made some crude repair that might have enabled them to get to subsonic flight, in which case they could jump out?" If they had concluded they had to do that rescue scenario, I mean, NASA is chock-full of brilliant, dedicated, fearless people, and you know they would have had all the astronauts beating the door down to fly the rescue mission.

Q: This was a very emotional, high-stakes investigation, and the board needed NASA's cooperation to get to the bottom of it. How did you go about asking NASA personnel the hard questions while maintaining good working relationships?

A: NASA is an organization that deserves a huge amount of respect, and they got a huge amount of respect from us. And so, yeah, sometimes in a particular interview, a particular question might be difficult or challenging, but for the most part, you went in there clearly conveying your respect. At the same time, we probed organizational flaws as early as we could, so it just seems to me like it worked out pretty well. There were 13 board members, but some of the individual investigators that we brought in were authorized to do the interviews, and if any of the board members felt that someone was crossing a line somewhere, we would intervene. I just think that there was just an underlying respect that was apparent. I remember Gehman going into the astronaut office and telling them, "You're the nation's heroes." His leadership was crucial.

Q: Adm. Gehman in particular went to great lengths to make sure the CAIB was independent. How aware were you and the other members of those struggles?

A: I wasn't aware of every aspect of the meetings and the disagreements and the discussion about whether the report would be fully released to the public. I felt like Gehman was very open and shared a lot with us, but I don't know what I don't know. On the writing of the report, I remember we brought in a guy named Dennis Jenkins, who was a very prolific writer.

Jenkins is the author of the 2001 book "Space Shuttle: The History of the National Space Transportation System." — CH

He was also really good at laying out the report logistically, and he was really instrumental in that. When we were done writing the report, he had the

▲ Retired U.S. Navy Adm. Hal Gehman (center), chair of the Columbia Accident Investigation Board, makes opening remarks during a June 2003 hearing. Steven Wallace is on the left, and at right is Douglas Osheroff, a Nobel laureate physicist who was one of the members later added to the board.

Rick Stiles

"The physical cause was pretty clear. The organizational stuff is more subtle, and it's something where you don't typically have a revelation. You just get an increasing sense of things like schedule pressure."

▲ Eighty-two seconds after the space shuttle Columbia lifted off from NASA's Kennedy Space Center for the STS-107 mission, one of the pieces of foam that separated from the external tank struck the orbiter's left wing. The Columbia Accident Investigation Board discovered such foam shedding was a frequent occurrence on shuttle flights, and NASA managers had come to consider this "an acceptable risk."

Scott Andrews

report on one compact disc, and he got in his Gulfstream jet and flew to have it printed. While he was flying out there, we would call him up and say we had some edits here, and he would edit it. He'd asked the pilots, "How many pounds of reports can I put on this?" It was something like 1,500 or 3,000, so he brought back a Gulfstream jet full of reports, and those were the initial copies of it. We took them to the families of the astronauts, and Gehman took one to [NASA Administrator] Sean O'Keefe. Then we released it to reporters. We did this in the NTSB hearing room, which is right in L'Enfant Plaza [in Washington, D.C.]. We gathered all these reporters, and we gave them each a copy of the record, and we locked them in a room and said, "You can just read this for the next hour or two. Then we'll have a public hearing and we will present it, and you'll be able to ask us questions."

Q: The CAIB concluded that NASA's culture had to change if it was going to have the chance of running a successful spaceflight program. You told reporters at the time you were pretty confident NASA could make that shift — has it?

A: I don't have any inside track to NASA at this point, so I don't know. And I don't know if the Artemis program is well-funded enough. I remember when Vice President Mike Pence said we're going back to the moon in 2024; I thought, "Yeah, that's not a vision for human spaceflight. That's a political statement." It's not a business issue, a vision for human spaceflight. You've got to get the country wound up and you have to fund it, and it's expensive. So I was skeptical. But now NASA has launched Artemis I, and I think it's good they're utilizing commercial companies. At the time of the report, some people claimed that the CAIB had suggested this was a bad idea. We did not suggest that or have opposition to using commercial companies. But let's consider the organizational things and substantial contributing factors to the Columbia accident. Could they happen again? I'm not in a business to say that, but NASA isn't making all those decisions anymore. Sometimes they're purchasing rides on private companies' vehicles. That's clearly different. ★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AI: HOW IT'S DELIVERING SHARPER ROUTE PLANNING

Planning a passenger aircraft's route has historically been a manual process for the specialists in airline operations centers. Now some dispatchers have a new tool: Artificial intelligence software that can rifle through weather, flight congestion and other data faster than a person can. This could be a timesaver, not just for dispatchers but for the flying public. Karen Kwon tells the story.

BY KARAN KWON | ykarenkwon@gmail.com

A few months ago, I hopped on an American Airlines flight from Memphis, Tennessee, to Washington, D.C., that was scheduled to depart at 3:55 p.m. Once everyone was aboard, the captain announced that our departure would be delayed, and he offered an explanation: We'd have to divert around a storm brewing over Nashville, and that meant we needed more fuel.

As we sat on the tarmac waiting for the fueling to be finished, I started to wonder if this delay could have been avoided.

It turns out that entrepreneurs in the artificial intelligence field have had scenarios like this one in mind for several years. As the technology is introduced into airline operations centers, the large rooms where dispatchers plan routes, it could reduce delays and missed connections while also making a dent in the carbon footprint of flight.

This is the story of how Alaska Airlines began working with Airspace Intelligence, a San Francisco-based startup with an office in Gdansk, Poland, to become the pioneer in the field. The story is based on inquiries to three airlines, plus interviews with executives at Alaska Airlines and Airspace Intelligence, and an analyst who watches the industry closely. Under a licensing agreement, Alaska Airlines dispatchers have been using Airspace Intelligence's Flyways software for two years now. The deployment has shortened average flight times, reduced fuel usage and carbon emissions, and contributed to its environmental sustainability goal, the airline says.

▲ Airspace Intelligence of California says its Flyways AI software can help airlines streamline operations by identifying alternative flight routes in the event of storms and other occurrences that would otherwise delay a flight. After completing a six-month trial in 2020, Alaska Airlines signed a multiyear contract with Airspace Intelligence in early 2021.

Alaska Airlines

Reinventing the dispatching process

The three founders of Airspace Intelligence, Phillip Buckendorf, Kris Dorosz and Lucas Kukielka — one German and two Polish immigrants — come from an autonomous driving startup that Buckendorf created in Palo Alto, California, in 2017. Working on the front line of an industry that had gotten a lot of attention — from media to venture capitalists to engineering talents — the founders could see that their field was getting crowded. This made them wonder if their specialty of using artificial intelligence to predict the future movements of other vehicles could be applied elsewhere in the transportation sector. So they started to explore how maritime and aviation were handling similar issues. Then in 2018, Alaska Airlines' head of corporate development, Pasha Saleh, who knew one of the founders, invited the trio to Alaska Airlines' operations control center in Seattle, officially known as the Network Operations Center, or NOC (pronounced "knock").

"We expected to see science fiction-like systems, like we know from movies," says Buckendorf, Airspace Intelligence's CEO. Instead, in Seattle and at the centers of other airlines they visited later, they saw dispatchers looking at old-fashioned IBM green screens, weather charts printed out on paper and operating software a decade or two old. The founders realized that there was a chance to innovate, which led to a decision to start a new company focused on aviation, Buckendorf says.

Creating a route requires a dispatcher to answer a host of questions such as: "What is the wind today?", "What is the best altitude for this flight?" and "Is there any military training?" Before the Flyways software, the 100 or so dispatchers at the NOC had to find answers to these questions by visiting multiple websites. These included FAA websites designed specifically for dispatchers, but that information was available only as strings of text that were hard to read.

Here's how Saleh describes the pre-AI days: "You have a tab open for the Weather Channel, a tab for CNN" and so on, he says. "So it's just click, click, click. If you look at a dispatcher, they have, like, 19 tabs open that they're flipping [through]."

A single dispatcher would typically be assigned about 20 flights to route, and manually assembled that information for each flight into a proposed flight plan for FAA. Airspace Intelligence believed it could modernize this archaic system.

Having decided to focus on the aviation industry, the team started spending an obscene amount of time at the NOC in an effort to understand how dis-

> "THE MACHINE IS REALLY GOOD AT CRUNCHING HUGE AMOUNTS OF DATA IN AN INCREDIBLE FAST AMOUNT OF TIME. WHAT THE HUMAN IS REALLY GOOD AT IS JUDGING THE SITUATION."
>
> — Phillip Buckendorf, Airspace Intelligence

patching works and to create a user-friendly product — one that a real dispatcher could seamlessly operate when under pressure. Alaska Airlines' employees would joke that the team was basically camping in their operations center with sleeping bags, Buckendorf says.

The attention paid off. After two years of intense development, Alaska Airlines agreed to try out the cloud-based software. The result of their efforts? During the airline's six-month trial period that started in mid-2020, dispatchers accepted 32% of the suggestions made by Flyways. Alaska Airlines then agreed to license Airspace Intelligence's proprietary software for a fee under a multiyear contract that began in January 2021.

Now, dispatchers no longer need to scour for data across multiple websites. Instead, the Flyways software funnels and displays the information for them. Plus, when a dispatcher is in the midst of planning a route on a computer screen, Flyways sends alerts about potential improvements. For example, the software could tell the dispatcher that by slightly changing the flight trajectory, the wind would be more favorable and the overall flight time could be reduced by seven minutes.

These suggestions are possible because of Flyways' machine-learning approach, in which the software improves itself by recognizing patterns between the input data — including weather and air traffic congestion — and the previous decisions that human dispatchers made based on that input. Then, once the software receives new data, it comes up with possible new routes.

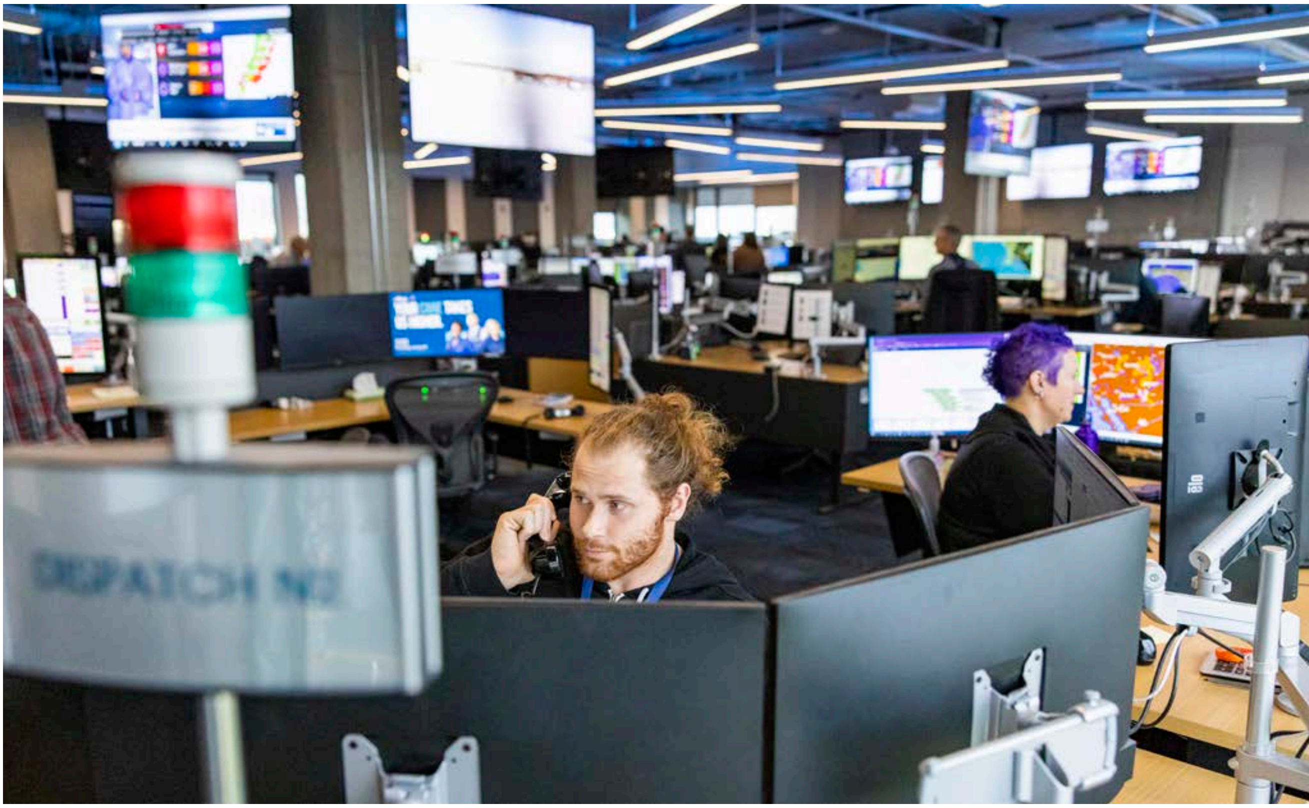
Even though the software is trained on historical data, it often presents options that are different from what dispatchers might otherwise have considered.

Humans have a tendency to stick with the familiar when planning a route between point A and point B. "But in reality, there's really an infinite amount of options of how you can travel from point A to point B," says Buckendorf.

Flyways improves itself further by learning from a human dispatcher's acceptance or rejection of its recommendations. When the dispatcher dismisses a suggestion, Flyways asks why: Was it because of the weather? Was the route putting an airplane uncomfortably close to somewhere it shouldn't be? The idea is that Flyways learns from those decisions and evolves — though certain data points need to be filtered out so that the software does not simply emulate human dispatchers' choices, stifling innovation.

"Now we've been using [Flyways] for over a year, the model is just getting better and better," Saleh says.

Buckendorf underscores that humans remain in control. "The machine is really good at crunching huge amounts of data in an incredible fast amount



▲ On any given day, about 100 or so dispatchers plan flight routes in Alaska Airlines' Network Operations Center, located on the sixth floor of "The Hub," a large building on the airline's Seattle campus.

Ingrid Barrentine/Alaska Airlines

of time," he says. "What the human is really good at is judging the situation."

He suspects that this dynamic likely will not change for a long time.

This hybrid structure between humans and AI has an added bonus: With humans in the loop, the software is only providing assistance under an existing process, so there is no need for additional oversight by FAA regulators, says Buckendorf.

Because route planning isn't a mission-critical activity and the routes are reviewed by FAA, the use of AI probably draws less scrutiny from regulators than, for instance, if AI were applied to avionics, says Peng Wei, an engineering professor at George Washington University in Washington, D.C.

Buckendorf and Saleh say that neither company has plans for a fully autonomous version of Flyways. The goal of implementing AI isn't to transfer a human job to a machine, Saleh says, especially when dispatchers are unionized. "We made sure from day one that the union realizes [Flyways] is not trying to remove dispatchers' jobs," he says. "It instead is a decision-support tool."

Reducing carbon emissions

Alaska Airlines calculates that between January and September 2022, Flyways saved an average of 2.7 minutes per flight, meaning that the airline avoided 6,866 metric tons of carbon dioxide emissions.

The reduction is important, says Saleh, adding that Alaska Airlines turned to AI in large part to reduce its impact on climate change. When the airline's board met two or three years ago, it decided to place environmental sustainability as Alaska Airlines' top priority. From there, the board looked into ways that the airline could achieve its goal — such as using sustainable aviation fuel. Another item that came up during that discussion was improving operational efficiency.

Some of the effects are also felt directly in the NOC. Traditionally, even when two dispatchers were sitting right across from each other, one would not be aware of what the other is up to. For instance, if both were handling flights landing at, say, Boston's Logan International Airport, they could inadvertently schedule the two flights to arrive at the same time, creating a conflict for local air traffic control to solve. In this scenario, the flights could be ordered to circle around Logan, resulting in unnecessary fuel usage and carbon dioxide emissions.

Flyways solves this problem by having all flights by the same airline on a single software, giving dispatchers a means to consider flights other than their own. "[At the] end of the day, as an airline, you are operating an entire system of flights, and they all impact each other," Buckendorf says.

To gauge the overall impact this emission reduction strategy might have in the fight against climate change, I emailed the International Council on Clean Transportation, a research nonprofit based in Washington, D.C. While the numbers Alaska Airlines reports

▲ This rendering illustrates how dispatchers in an airline operations center would see recommendations from Airspace Intelligence's Flyways software. The crisscrossing gold lines represent existing flight routes. When Flyways identifies a conflict, such as the weather front at the bottom right of that map, the algorithm internally simulates possible alternative routes before making its recommendation: the popup message at right.

Airspace Intelligence

are representative of what is to be expected, "it is not a huge reduction in fuel burn," writes Jayant Mukhopadhaya, an aviation researcher at ICCT.

The same statement can be applied more generally to using AI to plan routes. "[B]ut every little bit helps," he adds. "These operational improvements are low-hanging fruits that require minimal investment when compared to things like developing hydrogen-powered airplanes or fueling aircraft with sustainable aviation fuels."

That "every little bit helps" philosophy motivated the formation of the France-based company OpenAirlines by founder and CEO Alexandre Feray. Using various types of AI, the company's SkyBreathe platform examines almost every step of an airline's operation — including aircraft maintenance, flight preparations and flight operations — and finds areas where the airline can reduce fuel consumption.

But Feray cautions that "you won't solve everything with AI." Sometimes, physics-based models are needed instead of data-driven approaches like machine learning. Also, SkyBreathe currently doesn't consider contrails, and neither does Flyways. Feray explains that there currently isn't a clear, actionable item driven from sound scientific evidence that SkyBreathe can reference. And Saleh says Alaska Airlines' current use of Flyways is focused on reducing carbon emissions, but he believes the program is capable of taking contrail data into account for its decision-making process if the airline decides to pursue that direction in the future.

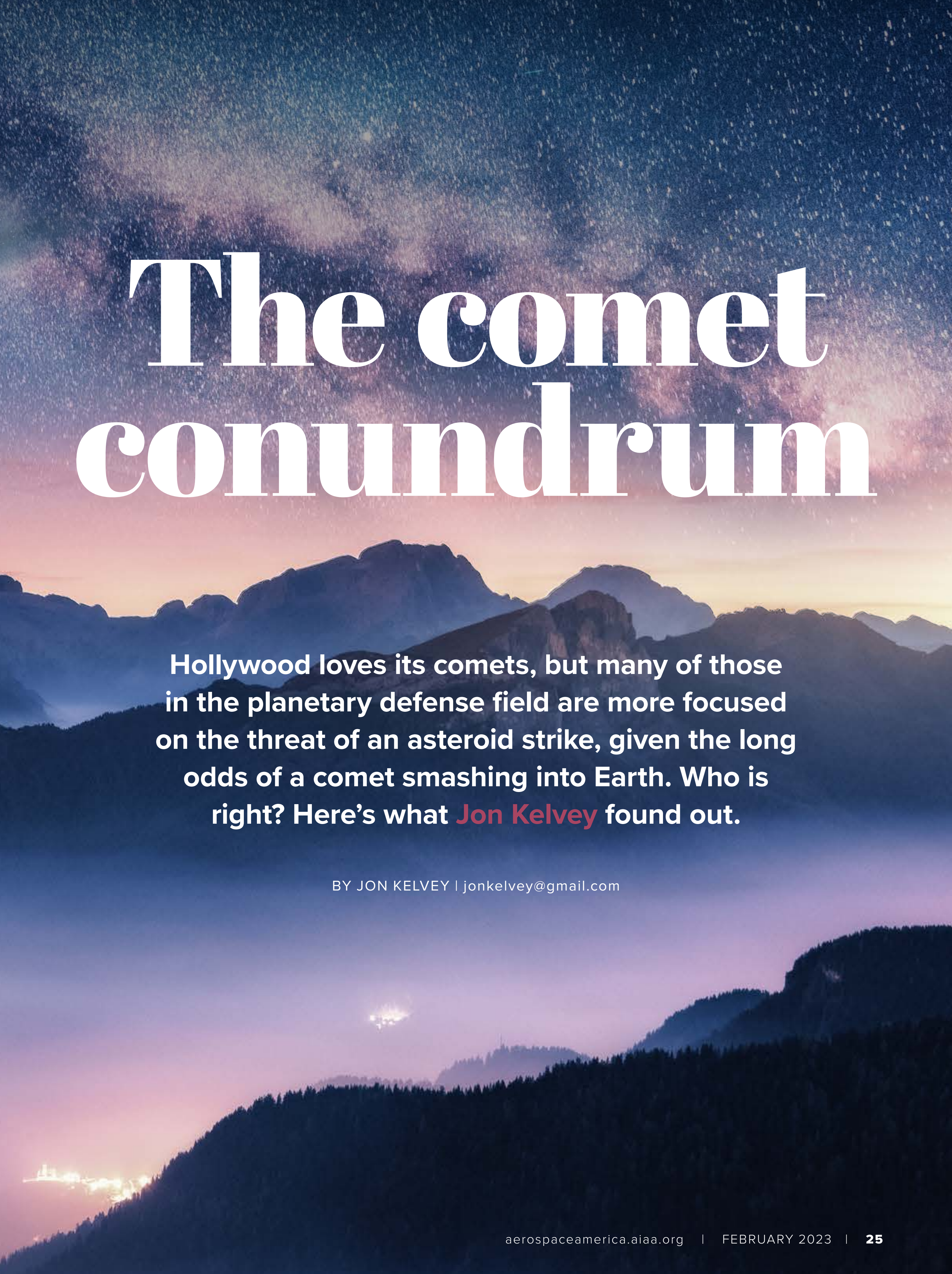
Feray predicts the use of AI to expand across the industry, especially when it comes to reducing its carbon footprint.

"We are lucky to be in an industry where you can be more environmentally friendly and, at the same time, improve your bottom line," he says. He also suspects that, while the current technology relies on historical data, the advancements toward providing real-time data will enhance AI's reach within the industry.

Buckendorf tells me that Airspace Intelligence is in talks with other airlines, though he and company aren't ready to announce anything yet. And while he is unaware of other airlines using AI to help dispatching, Wei of George Washington University speculates that bigger airlines with their own research and development teams could be developing their own AI dispatching solutions while exploring options for hiring an outside vendor to develop such technology. Wei himself was scheduled to give a talk at American Airlines, his former employer, to the airline's operations researchers about using machine learning to aid decision making.

As for my flight from Memphis to Washington, D.C., American Airlines says the company currently does not use AI in route planning. Could Flyways have created a new route in time for my plane to receive the necessary amount of fuel and avert the delay?

"100%," Buckendorf says. ★



The comet conundrum

Hollywood loves its comets, but many of those in the planetary defense field are more focused on the threat of an asteroid strike, given the long odds of a comet smashing into Earth. Who is right? Here's what Jon Kelvey found out.

BY JON KELVEY | jonkelvey@gmail.com

In 2013, a previously undetected asteroid the size of a house entered Earth's atmosphere over Chelyabinsk, Russia. NASA said the asteroid, estimated to be between 17 and 20 meters in diameter, was too small and dark for its telescopes to detect beforehand.

Alex Alishevskikh

Astronomers who specialize in spotting dangerous objects headed our way are not above conjuring their own scenarios like those in the 2021 dark comedy "Don't Look Up."

Here's one of them: It's April 4, 2024, and astronomers looking through a ground-based optical survey telescope have just discovered a new comet, its icy nucleus steaming in the sunlight to produce a characteristic tail as it passes inside the orbit of Saturn. The roughly 1-kilometer-wide dirty snowball will cross Earth's orbit in just 22 months. Astronomers cannot be certain yet, but the odds are much higher than anyone is comfortable with that the comet could crash into us in late February 2026.

If you were in charge of NASA's Planetary Defense Coordination Office, as Lindley Johnson is, you could take some comfort in the success of a mission conducted two years earlier with a different class of objects. The agency's Double Asteroid Redirection Test, or DART, mission showed that a kinetic impactor could nudge an asteroid and alter its orbit.

"This demonstrates we are no longer powerless to prevent this type of natural disaster," Johnson said in a statement following DART's impact on the asteroid moonlet Dimorphos. Combined with a comprehensive catalog of all the hazardous asteroids, "a DART successor could provide what we need to save the day."

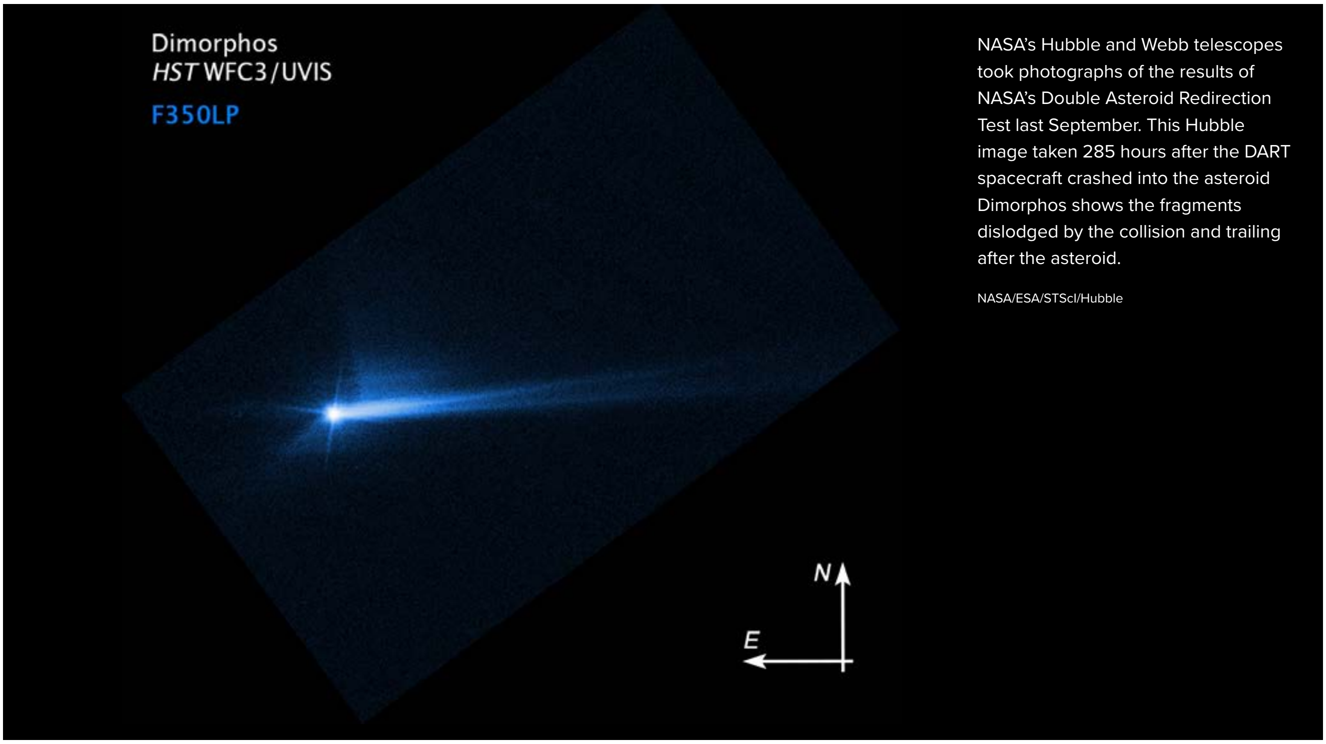
But DART targeted an asteroid, and comets are not asteroids. Comets falling into our solar system are more difficult to detect, their paths are tougher to predict because they off gas sublimating volatiles like water and carbon dioxide ice, and they're harder to deflect because, on average, they are much larger. Discover a potentially hazardous asteroid, and you can predict its potential close passes with Earth for years or decades, but comets don't often work that way.

All of which is to say that when it comes to comets, "two years' warning is really, really short unless you've prepared a lot on the ground," says Paul Chodas, director of the Center for Near Earth Object Studies at the NASA-funded Jet Propulsion Laboratory in California. He designed the above scenario, with different dates, for the fourth annual Planetary Defense Conference in 2019 to get people thinking about the threat from comets. Because even though the odds of a comet strike are astronomically low — in fact, much lower than an asteroid strike — "the consequences would be devastation, global devastation, for even a relatively small, long-period comet."

Johnson tells me that the efforts his office continues to make to detect hazardous asteroids will inevitably help discover more comets. Other groups at NASA have contemplated comet interceptor spacecraft, while some researchers in California even envision directed energy tools, giant lasers, to help redirect

This photograph taken by the Light Italian CubeSat for Imaging of Asteroids shows the plume created when NASA's Double Asteroid Redirection Test spacecraft, DART, slammed into the asteroid Dimorphos in September (bottom right). The cubesat separated from DART ahead of time to photograph the collision.

ASI/NASA



NASA's Hubble and Webb telescopes took photographs of the results of NASA's Double Asteroid Redirection Test last September. This Hubble image taken 285 hours after the DART spacecraft crashed into the asteroid Dimorphos shows the fragments dislodged by the collision and trailing after the asteroid.

NASA/ESA/STScI/Hubble

comets in dangerous orbits.

The ideas range from potentially feasible to fantastic in terms of their practicality, which may be exactly where the thinking needs to be at the moment. DART was an impossible dream for the whole history of life on Earth until less than a year ago, and with millions of years expected between significant comet strikes, there's potentially plenty of time — so long as you don't wait till the last minute.

Comets are different

In the original script for "Don't Look Up," director Adam McKay used a 100-kilometer-wide asteroid, knocked mysteriously off course, to drive his climate change allegory, an exploration of society dealing with an impending global disaster. But wanting a degree of realism rather than pure deus ex machina, McKay consulted with Chodas and his center about this massive plot device.

Comet Hale-Bopp flew by Earth in 1997, two years after its discovery. One of the brightest comets to reach the inner solar system, its white and blue tail was visible to the naked eye for nearly 18 months starting in May 1996. A camera aboard the space shuttle Columbia took the above photo of the comet, and the photo at left is a 10-second exposure taken by Austrian astronomers.

Erich Kolmhofer and Herbert Raab, Johannes-Kepler Observatory; NASA

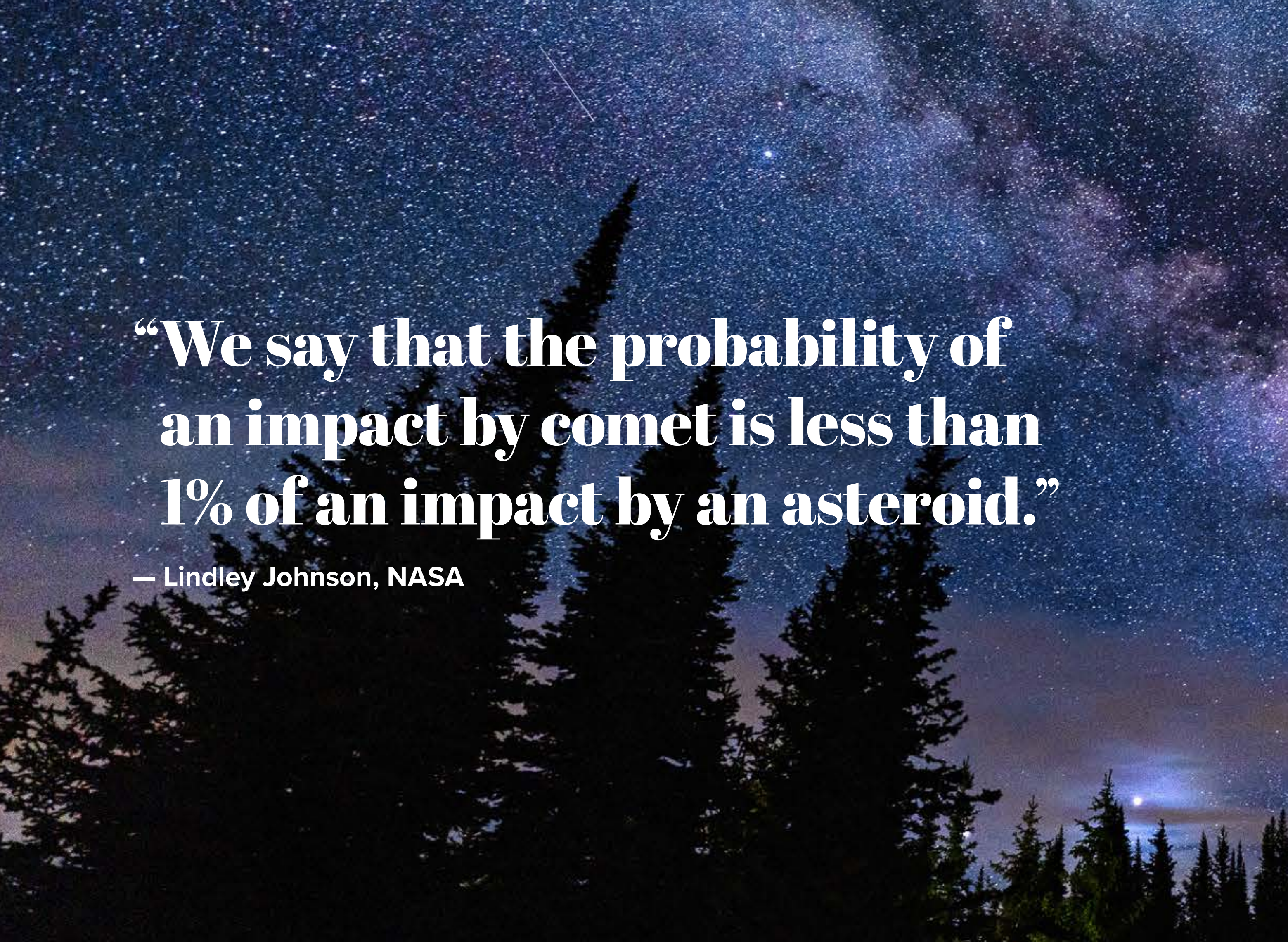
* **OSIRIS-REx** is short for "Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer

"I read the early version of his script, and I indicated that what he had proposed was so far-fetched that he should consider something else," Chodas says. "If he wanted to consider a plausible major impact event with global effects, extinction level, if you will, that what was plausible was a long-period comet impact."

Long-period comets are different from Jupiter-family comets, which typically traverse their elliptic orbits in 20 years or less. Long-period comets can take thousands or tens of thousands of years to orbit the sun, such that the few that fall into the solar system each year may never have been seen before. Falling in from the icy Oort Cloud anywhere from 10,000 to 100,000 astronomical units out from the sun, they are almost invisible until they get close enough to the sun to begin thawing and leaving trails of dust and gas — the comet coma — somewhere between the orbits of Saturn and Jupiter.

That doesn't leave long between sighting and warning, about the 22 months that Chodas built into his scenario. To take a real-world example, Comet Siding Spring (C/2013 A1) was discovered on Jan. 3, 2013, inside the distance of Saturn's orbit, about 7 AU, and made a close pass of Mars on Oct. 19, 2014.

"It took them about six months to figure out that it wasn't going to actually hit Mars," says Joseph Nuth, a chemist at NASA's Goddard Space Flight Center in Maryland and member of the OSIRIS-REx* asteroid sample return mission science team, as well as a member of a Goddard group studying hazardous impact threats. "Out of those 22 months, basically, six are already gone to try to figure out whether or not it's going to hit Earth."



That’s already bad enough, but long-period comets also “have weird orbits with respect to Earth’s orbit,” says Derek Richardson, a University of Maryland professor of astronomy and DART team member. While asteroids tend to orbit in the plane of the ecliptic — the plane of Earth’s orbit around the sun — long-period comets can come from any direction, which means the relative speed between the comet and Earth is higher, he says, “and of course, the energy of the impact is proportional to the mass, but to the square of the relative speed.”

Long-period comets typically travel at around 65 kilometers per second in the inner solar system, so in Richardson’s judgment, “they are bad news.”

And the mass of long-period comets is nothing to sneeze at either. “They don’t come in tiny sizes,” Chodas says. “They usually are roughly a kilometer, not much smaller than half a kilometer in size, because the smaller ones have just simply fallen apart over the eons.”

Comet Hale-Bopp, which passed through the solar system in 1997 and won’t return until 4385, was about 40 kilometers in size, he adds.

It’s not entirely clear which impacts in Earth’s history may have been comets. The Tunguska event of 1908 saw some kind of object bursting in the air over Siberia with the force of 12 megatons, flattening 2,000 kilometers of trees. Arguments have been made for the object being a meteorite or a comet fragment. Some evidence suggests a large comet fragment bursting in the air over North America just shy of 13,000 years ago may have kicked off a millennia-long cooling period in the region despite Earth’s climate swinging out of an ice age at the time. The Chicxulub impact in the Yucatán Peninsula 65 million years ago that generated a 100 million-megaton blast and wiped out the dinosaurs is believed to have been an asteroid but gives a flavor of what a comparable comet could do to Earth. It would be worse.

Planning for unlikely calamity

The good news is that the risk of a long-period comet threatening Earth is extremely unlikely: “We say that the probability of an impact by comet is less than 1% of an impact by an asteroid,” NASA’s Johnson says.

Still, it’s possible, and one would like to know there’s something that could be done if a 1-kilometer-diameter comet were discovered tomorrow with Earth in its crosshairs. Thankfully, the DART mission

does provide a potential template for a response.

"If we were faced with a comet and all we had was a kinetic impactor, well, that's probably the technology that we would use to try to change its orbit," Johnson says. "Remember that you don't need to send just one kinetic impactor to the target. We could send a series of kinetic impactors and then slowly punch it into a new orbit, so to speak."

Targeting a comet would be more difficult than an asteroid because comets in the inner solar system constantly emit jets of sublimating gas and dust, the source of their comas, which perturb their orbits. But this could be used to our advantage, according to Johnson, so that an impactor could create a bigger effect on the comet's orbit than that created just by transferring its energy into the object.

"An impactor would expose more material, volatile material in the comet," he says, "creating an even bigger, natural jet of gasses from the comet within and then change its orbit even more."

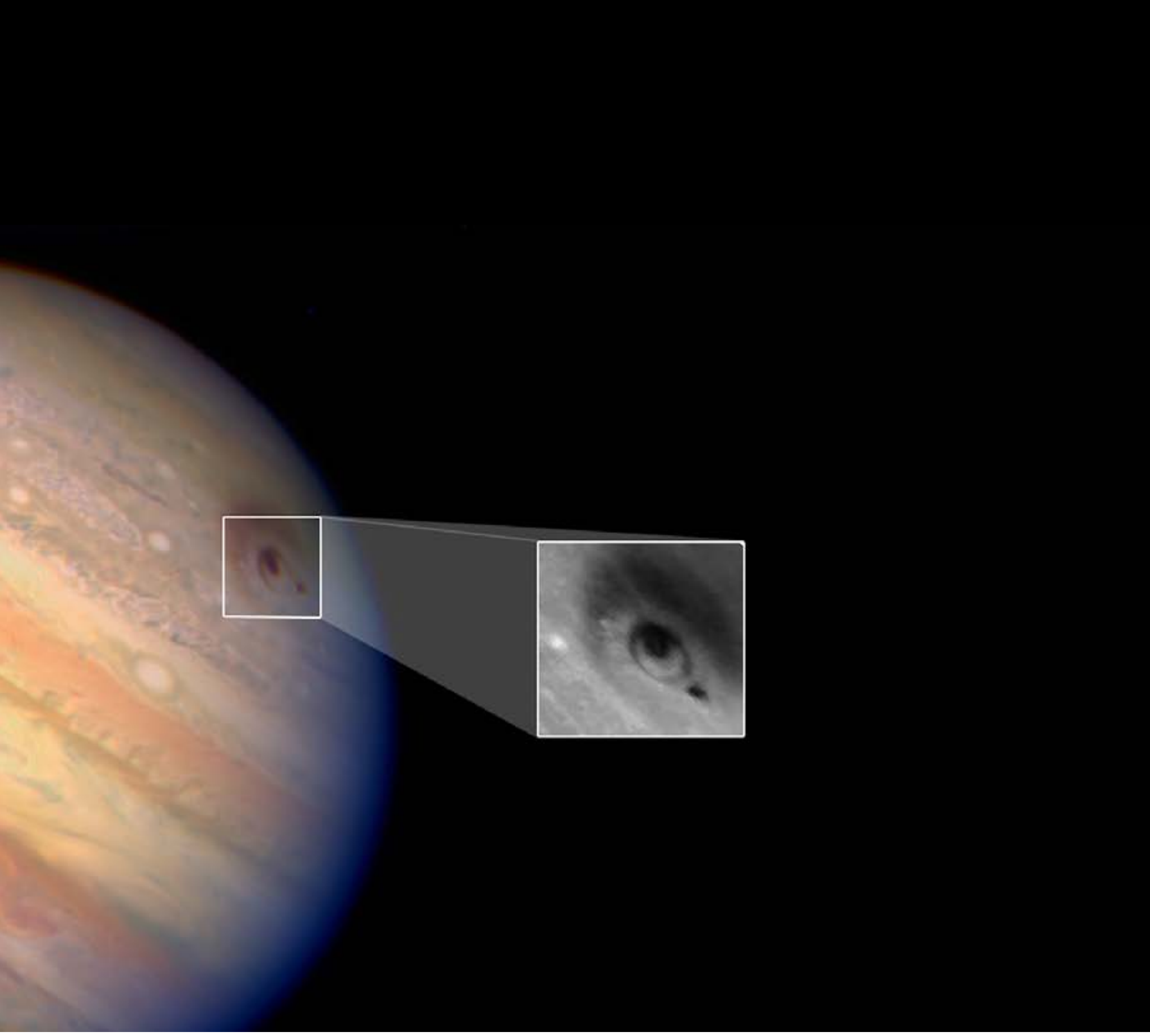
And a kinetic impactor might need that extra help.

The target of the OSIRIS-REx mission, the half-kilometer-wide asteroid Bennu, makes an excellent stand-in for a comet's nucleus, according to Nuth. He speculates that Bennu might be a dead comet, stripped over eons of its volatile icy shell. In a computer model simulating what would happen if Bennu were on a collision course with Earth, it took 87 kinetic impactors roughly six times more massive than DART to alter the asteroid's orbit enough so that it missed Earth.

"Launching 87 would be almost impossible," Nuth says. "We don't have enough launch sites."

Nuth's preferred solution would greatly reduce the number of launches necessary to redirect a comet: "You really need a spacecraft that will be able to carry a reasonably sized nuclear weapon," he says. Take a 1-megaton nuclear explosive device and detonate it at about 100 meters from the comet's surface, and the X-rays and gamma rays penetrate 10 to 20 meters deep at the speed of light. That heats the entire hemisphere of the comet facing the explosions, and "it all turns into a plasma at that point," Nuth says, "which means that you get one hell of a kick on the rest of the body."

When he used a nuclear device in his Bennu deflection model, Nuth found it took one explosion to deflect the asteroid, compared to the 87 kinetic impactors.



This is one of the sites where fragments of Comet Shoemaker-Levy 9 crashed into Jupiter over a period of six days in July 1994. Photographed by NASA's Hubble Space Telescope and Galileo orbiter, they were the first observed impacts between two objects in the solar system.

NASA and H. Hammel, MIT

Going nuclear carries its own problems, of course, not least of which would be the large amount of legal infrastructure necessary to even begin seriously thinking about putting a nuke on an outbound rocket. But it also shares a major problem faced by kinetic impactors, namely that "it takes about 36 to 48 months to put a spacecraft together once you've done all the reviews and all the testing," Nuth says. "You just don't necessarily have the time for that."

So Nuth proposes some preparation. NASA could build two spacecraft — a reconnaissance craft, which would be launched to intercept and study a threatening comet, and a mitigation craft, which would be launched carrying the nuke, if deemed necessary. Both spacecraft would be stored in a warehouse until needed, ready to be launched with a short warning. To help make more palatable the idea of spending billions on spacecraft that might never be used for their primary purpose, Nuth also suggests replacing the craft every 20 years or so with new models using the latest technology, and then releasing the old craft for science missions.

"The reconnaissance satellites, for instance, can certainly go on a planetary mission," he says. "They've been built to do that."

But even with Nuth's twin spacecraft or a fleet of DART-like impactors ready to fly, long-period comets could be difficult to deflect if their orbits are strange enough. A comet coming in orthogonal to the plane of the ecliptic would present a huge challenge, according to Chodas.

"It's very difficult to get a spacecraft out of the plane of the ecliptic without a gravity assist," he says. "And on short warning, you wouldn't really have an opportunity for a gravity assist."

One team of researchers has a radical idea for getting around that problem too, ditching the need for a spacecraft altogether. In a 2019 paper, Gary Hughes of Cal Poly, Philip Lubin of the University of California at Santa Barbara and Caltech graduate student Qicheng Zhang envisioned a massive orbital laser array that could heat a comet's surface at a distance, generate targeted off gassing and change its orbit.

"A 10 gigawatt, 500-meter laser array operating for 1% of the time over 1 year can deflect a 500-meter comet," Zhang wrote in an email.

But Zhang readily admits that constructing and maintaining a 10-gigawatt power source, not to mention a half-kilometer or larger laser array, is a daunting and expensive task unlikely to be undertaken merely as a hedge against an astronomically unlikely disaster. So like Nuth and his spacecraft, Zhang envisions a dual purpose: Perhaps implementing a

comet deflection program through a laser array constructed for propulsion purposes, such as the Starshot Breakthrough Initiative that aims to project laser light onto a light sail attached to a nanospacecraft to propel it to the nearby star Proxima Centauri.

More eyes on the sky

Other techniques for mitigation have been contemplated, including some of those also being explored at NASA for diverting hazardous asteroids, according to Johnson. He would like to test the gravity tractor technique on an asteroid at some point, which is when a spacecraft keeps pace with the object over a long period, using their mutual gravitational attraction to change the object's orbit.

All approaches to comet strike mitigation, from impactors to lasers, are challenged by the reality of responding to a hazard on short notice and the unlikelihood of winning funding for expensive mitigation projects before knowing a threat is actually on the horizon.

This is why the best strategy for dealing with dangerous comets may be the same as dealing with hazardous asteroids — trying to find more of them, and find them earlier.

"If you're going to invest in technology, we need better ways of finding dark comets farther away from the sun," Chodas says, because cold and distant comets are difficult to see until they warm up as they get closer to the sun. "Detection is your best investment."

The Vera Rubin Observatory, set to begin operations in Chile in 2024, could be a boon for the detection of long-period comets, for instance. Also, "Our new project, the Near-Earth Object Surveyor, will be a space-based telescope operating in the infrared part of the spectrum," Johnson says. "It will be a very good comet finder as well."

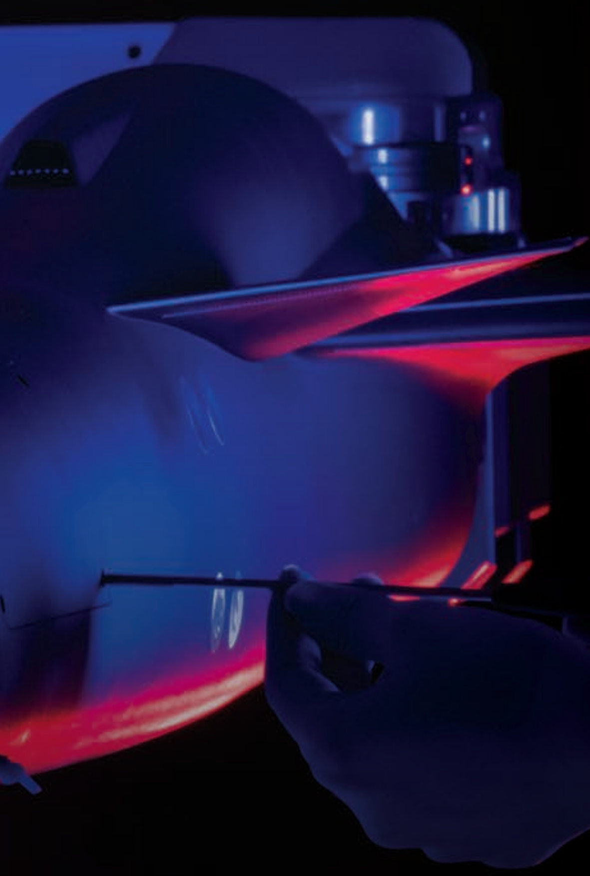
Still, neither NEO Surveyor — which is scheduled for launch in 2028 — nor the Rubin observatory will be capable of detecting long-period comets with much more warning than is possible today, according to Chodas, who says such capability is another generation of technology away.

But odds are that will be OK. Asteroids are a more likely, if still ultimately unlikely, threat, and one we can do something about, even if more work remains. So in some sense, cometary planetary defense is right where it needs to be, Chodas says: a conceptual add-on to efforts to mitigate asteroids today that may become the cutting edge in the field in another 100 years, once all potentially hazardous asteroids are accounted for.

"Nonetheless," he says, "it's certainly interesting to think about what we would do." ★

▲ When NASA's OSIRIS-REx spacecraft touched its sampling arm to the surface of the asteroid Bennu in 2020, researchers were surprised to discover large amounts of loose particles instead of densely packed rocks and dirt. NASA chose the 500-meter-wide asteroid for the sampling attempt because there is a 1-in-1,750 chance that it could hit Earth in the next 300 years.

NASA/Goddard/University of Arizona



Supersonic

Engine design will be key to reviving commercial supersonic air travel in a way that is affordable and environmentally palatable. After a setback in September, Colorado-based Boom Supersonic believes it now has the right engine team and approach. Aaron Karp tells the story.

BY AARON KARP | aaronkarp74@gmail.com

twist

Anyone on hand when British Airways flight BA002 touched down in London in October 2003, bringing an end to the Concorde era, would have seen a design and clientele far different than those planned today by Boom Supersonic. The well-financed Colorado company is attempting to lead the industry back into the business of supersonic air travel, this time hopefully for good. The Concorde's nose, as always, was drooped forward during landing and taxiing to permit the flight crew to see. Once on the tarmac, its four Rolls-Royce/Snecma Olympus 593 engines spooled down. Among the passengers who disembarked were, reportedly, model Christie Brinkley, actress Joan Collins, talk show host David Frost and journalist Piers Morgan, then the editor of the Daily Mirror newspaper.

By contrast, Boom Supersonic and its startup competitor Exosonic Inc. of California are targeting not the rich and famous, but those willing to pay business class prices. In fact, the demise of the Concordes has often been blamed largely on an overreliance on wealthy consumers. Each aircraft's immense operational costs, driven by high fuel burn, meant even extraordinarily high fares could not make them profitable. On top of that, the confidence of travelers was shaken when an Air France Concorde crashed on takeoff from Paris in 2000, killing all 109 aboard and four on the ground.

Exosonic has established a much longer timeline than Boom, which means that dreams of reviving supersonic air travel anytime soon hinge on the new team that Boom has assembled to create a "clean sheet" engine that will operate with acceptable

▲ Instead of modifying a current subsonic engine design, Boom Supersonic of Colorado in December said it would design a brand-new engine for its Mach 1.7 airliners, shown here in a rendering. Each Overture would be powered by four Symphony turbofans.

Boom Supersonic

maintenance costs and provide carbon neutral thrust by burning 100% sustainable aviation fuel made from replenishable sources rather than fossil fuel. Plans had called for Rolls-Royce to adapt an existing engine design, but in September, Rolls confirmed in media reports that it would no longer participate in the project. This prompted Boom to announce the new team in December and give the proposed engine a calming name: Symphony. Four Symphonies are to propel each of Boom's planned Overture jets.

"As Boom has matured the Overture program, we listened to our partners and customers and learned that applying the current subsonic engine model to our supersonic airliner would not be the most economically sustainable solution," said Troy Follak, senior vice president of Boom's Engineering and Program Office, by email. "By developing a new engine, Boom can provide significant savings and benefits for airlines and passengers."

The team's makeup is unconventional compared to past engine efforts: The engine will be designed by Florida Turbine Technologies, the unit of Kratos Defense and Security Solutions that helped design the engines for the U.S. Air Force's F-22s and multiservice F-35s; GE Additive of Cincinnati will provide advice about 3D printing components; and StandardAero, an aviation maintenance company in Scottsdale, Arizona, has the task of making sure the Symphony engines will be maintainable.

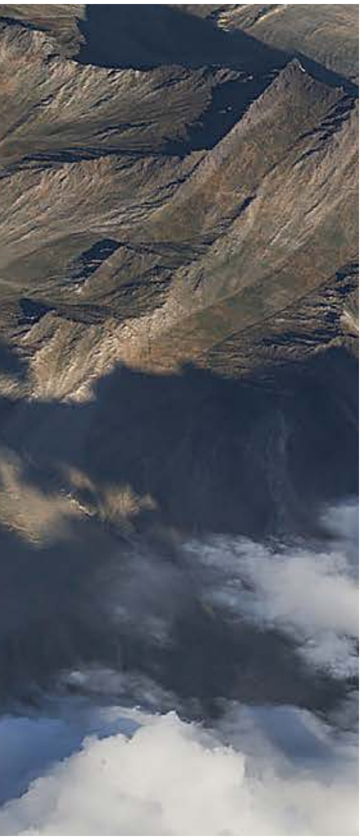
Symphony will be a twin-spool, medium-bypass turbofan engine producing 155,693 newtons (35,000 pounds) of thrust. Overture is being designed to fly at Mach 1.7, slower than the Concorde, which could reach speeds just over Mach 2. Even so, when or if Overtures fly, passengers will be able to get from New York to London in 3.5 hours and from Seattle to Tokyo in 4.5 hours, Boom says.

Given the Concorde's history, affordable flying is a top priority for Boom. A Concorde flight ticket typically exceeded $10,000 during the fleet's 1976 to 2003 in-service lifespan. Most Americans and Europeans could only fantasize about enjoying high-speed trans-Atlantic travel. Boom expects its planned Overture aircraft, at least in their initial years of operation, to have fares of $1,000 to $2,000, in line with today's long-haul business-class ticket prices. Boom is aiming for an operating cost that's 75% less compared to the Concorde.

As for the timeline, Boom believes that it can develop the new engine in time to conduct the first Overture test flight in 2027 so the aircraft can be certified by 2029 by FAA and EASA, the European Union Aviation Safety Agency. Airlines could then commence commercial flights in 2030.

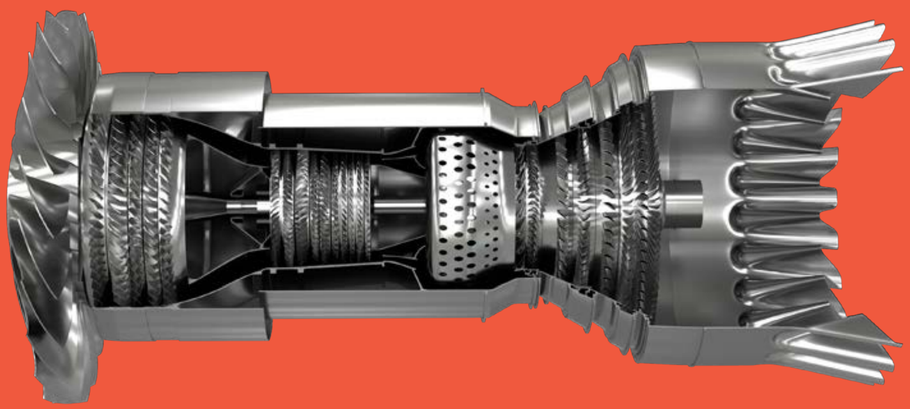
Is that schedule feasible? Chris Combs, an assistant professor and expert in high-speed aerodynamics at the University of Texas at San Antonio, calls it "ambitious" and the schedule "aggressive."

Like Exosonic, another developer is taking a



▲ Exosonic Inc. of California released this illustration of its planned supersonic airliner in May, when the company completed a conceptual review of the design with the U.S. Air Force. The company plans to first develop a supersonic drone that would fly in 2025 and help refine the airliner design.

Exosonic Inc.



In contrast to the Concordes' Olympus 593 turbojet engines that compressed incoming air for combustion and had afterburners for creating additional thrust, Boom Supersonic's Symphony engine (a rendering is displayed above) will be a turbofan design.

Boom Supersonic

slower approach. Though there is "exceptional hype in the race to be first," it will take time "to reintroduce supersonic flight that is responsible, quiet, fuel-efficient and environmentally sound," said Max Kachoria, CEO of Spike Aerospace, by email. The Boston company has been in semi-stealth mode since 2021 and has not announced a target date for its Mach 1.6 business jet, which has been in development for almost a decade.

He added that "too often the first to market introduces a minimally viable product."

Long shadow

The U.S. general public's early experience with supersonic flight was the loud sonic booms generated by military jets. In 1968, with the Concorde on the verge of achieving first flight, Congress directed FAA to "prescribe and amend standards" for aircraft noise and sonic booms. This led to the agency's 1973 ban on civil supersonic flight over land — a serious impediment to the success of the Concorde, then still in the midst of flight testing. Only 20 were ever built by France's Aerospatiale and the British Aircraft Corp., the British-French joint venture that developed the aircraft in the 1960s. Concorde made its first test flight in 1969, the same year as the moon landing, a heady time for achievement in flight. Six of the 20 Concordes were devoted to the five-year test flight program and only 14 were ever operated by airlines — seven each by British Airways and Air France.

After the Air France crash, both fleets were grounded by regulators for more than a year. The Concordes returned to service in November 2001, but matters from there unfolded more like a denouement.

Today, freeing themselves from Concorde's shadow remains a top priority for Boom and Exosonic. Each company says its new aircraft will be quite different from the original.

For Boom, that means constructing Overtures out of carbon composites instead of aluminum. Overture's wingspan will be 7 meters longer than Concorde's (32 meters versus 25 meters), with a gull wing design that has a curved inner section, a subtle contrast to Concorde's delta wings. A more noticeable difference: Overture's pointed nose will remain so during takeoff and landing in a departure from the famous "drooped nose" designers adopted to maximize pilots' visibility on the Concordes. Boom says that particular feature made the aircraft heavier and likely extended the certification process, so it instead plans to design Overture with a "virtual forward window" via external cameras. The company is testing this artificial vision system on its subscale demonstrator, XB-1, affectionately nicknamed "Baby Boom."

A number of airlines appear to believe in the future of supersonic flight, contending there will be demand among the public for super-fast airline trips. American Airlines, Japan Airlines, Virgin Atlantic Airways and United Airlines have all placed provisional orders for the Overture, with American taking the step of paying a nonrefundable deposit in August on 20 aircraft. The airline declined to specify the dollar amount of the deposit when I asked.

Fresh approach

In an unconventional twist, none of the big three aircraft engine manufacturers — General Electric's GE Aerospace, Pratt and Whitney, and Rolls-Royce — will be involved in the Symphony program. Rolls backed out after two years of research cooperation toward a potential engine.

In contrast to Boom Supersonic's sole focus on a passenger airliner, Exosonic Inc. of California first plans to develop a supersonic uncrewed aerial vehicle, an illustration of which is shown here. That work is partially funded by a Small Business Research Innovation award from the U.S. Air Force's AFWERX division.

Exosonic Inc.

"They've got an interesting team they've put together and a lot of smart people who know a lot about aircraft engines, so I think they're capable. But even in a best, best-case scenario, the timeline is ambitious and it's going to take them a while."

— Chris Combs, University of Texas at San Antonio

"After careful consideration, Rolls-Royce has determined that the commercial aviation supersonic market is not currently a priority for us and, therefore, will not pursue further work on the program," Rolls said in a statement in response to my inquiry.

Rolls and France's Snecma jointly produced the Olympus 593 engine that powered the Concorde.

Boom, for its part, says its research with Rolls led it to the conclusion that a derivative of a current in-service engine was not viable. That said, Boom says the envisioned "clean sheet" engine will borrow technology and design elements from currently operated commercial aircraft engines.

Follak, the Boom executive, underscored that this won't be a vendor arrangement: Boom will "have full control and ownership of the design" for the engine.

GE Additive's involvement could signal that GE Aerospace, the parent of the unit, might take a bigger role in the Symphony program in the future, though this is far from certain.

"There are not that many companies in the world that produce commercial jet engines that run on passenger aircraft," says Combs, the assistant professor. "There's a reason for that — it's really hard to do."

But he does believe FTT, as Florida Turbine Technologies is known, could very well succeed, even if he questions the timeline.

"They've got an interesting team they've put together and a lot of smart people who know a lot about aircraft engines, so I think they're capable. But even in a best,

Supersonic showdown

A few years ago, the race to revive supersonic travel appeared to be heating up. But today, only Boom Supersonic of Colorado and Exosonic Inc. of California are openly discussing their plans and progress toward certifying their proposed aircraft. Here's where they and their potential competitors stand.

	Proposed aircraft	Speed	Business plan	Entry to service target	Status
Aerion Supersonic of Nevada Shut down in 2021 due to lack of funding.	AS2, a business jet with 10-12 seats	Mach 1.6	Begin test flights in 2024 with the AS2, marketed toward wealthy travelers. In 2021 announced the A3, a 50-seat passenger airliner that would fly at Mach 4.	2026	Assets have been liquidated.
Boom Supersonic of Colorado	Overture, a passenger airliner with 65-80 seats	Mach 1.7	Receive FAA and EASA type certification by 2029. Airlines would sell tickets at business-class prices.	2030	Plans to begin test flights with XB-1, a subscale demonstrator, this year. As of January, four airlines had placed provisional orders for a combined 140 Overtures.
Exosonic Inc. of California	A yet-unnamed 70-seat passenger airliner	Mach 1.8	Develop an uncrewed supersonic drone for the U.S. Air Force that would help refine the design for the passenger airliner.	2025 for the supersonic drone No date announced for the airliner	In May, completed a conceptual review with the U.S. Air Force of the airliner design. Has a Phase II Small Business Innovation Research grant from the Air Force's AFWERX to develop technology for the drone and the airliner.
Spike Aerospace of Boston In "semi-stealth mode" since 2021.	S-512, a business jet with 12-18 seats	Mach 1.6	On its website, Spike describes its business jet as an "ultra-premium corporate aircraft" for "private air travel."	Has not said	Has not provided a public update recently. Flew its SX-1.2 subsonic test aircraft in 2017 to help prove technology that would be used on the S-512.
Virgin Galactic of California Has not provided an update since 2020.	A yet-unnamed airliner with 9-19 seats	Mach 3	In 2020 announced a "first stage design" on a passenger aircraft and a "non-binding" partnership with Rolls-Royce to explore developing an engine.	Has not said	A spokesperson says the company's focus currently is on spaceflight. Rolls says it is no longer working on the project.

SHUT DOWN ACTIVE STATUS UNCERTAIN

best-case scenario, the timeline is ambitious and it's going to take them a while," Combs says. "Four years would be a really, really short amount of time to get this engine tested and integrated onto an airframe and then actually up in the air" for a first test flight in 2027.

Boom's competitor Exosonic appears to agree. The company firmed up its supersonic aircraft design in early 2022, but has shifted its focus to first developing a supersonic drone, targeted to begin flying in 2025. When I asked about this slower approach to passenger transport, Exosonic CEO Norris Tie cited the lack of interest by the major manufacturers in developing an engine.

A new commercial supersonic engine is "10-plus years away," says Tie.

Overland challenge

It's tempting for designers to count on beginning the acceleration toward supersonic speeds by injecting fuel into each engine's hot exhaust, but these afterburner mechanisms are loud. Concorde's Olympus 593 engines each had an afterburner. NASA's X-59 supersonic test aircraft has one on its single GE Aerospace F414-GE-100 engine, a design similar to those on U.S. Navy FA-18E Super Hornets. Installation of that engine was completed in November in preparation for the first X-59 flight, planned for later this year.

The point of the X-59, however, is not to prototype a commercial supersonic design or even to demonstrate low engine noise. The goals are to show that a sonic boom audible to people on the ground can be averted through design tweaks and find out if the resulting "sonic thump" will be tolerable to residents. To find out, a NASA pilot will steer the X-59 overland at a high altitude, too high, in fact, for engine noise to be heard on the ground. The shockwave at the front of the aircraft will be minimized by smoothing the cockpit with the nose, while an "aft deck" at the tail end "reflects shock waves from the engine exhaust upwards, thus preserving the low boom signature that travels to the ground," explained Craig Nickol, NASA's senior adviser for integrated aviation systems, via email.

If things go as hoped, international and national regulators will see the X-59 results and lift the current ban on overland supersonic flight, provided the aircraft make only a sonic thump.

Regarding the afterburner, Nickol said X-59 will be "operating on an experimental basis from installations that can accommodate" higher takeoff noise. "In addition, the X-59 may not require the afterburner for takeoff depending on the particular operating conditions present," he says.

James Bridges, NASA's airport noise tech lead on the Commercial Supersonic Technology program, added via email: "Bottom line, commercial supersonic transports will not be able to use afterburners during takeoff and landing because they would be so loud."

No one has to convince Boom that afterburners are undesirable. "One major difference from 1970's-designed supersonic engines is that the Symphony engine enables

▲ Boom is targeting 2027 for the first flight of an Overture airliner, shown here in an illustration, and 2029 for receiving type certification from FAA and the European Union Aviation Safety Agency. The company's preorders include 20 aircraft from American Airlines and 15 from United Airlines.

Boom Supersonic

"By developing a new engine, Boom can provide significant savings and benefits for airlines and passengers."

— Troy Follak, Boom Supersonic

supersonic flight without afterburners, which make military supersonic aircraft notoriously noisy," Boom's Follak said, noting that the Concorde's engines "were not designed to meet the emissions or noise requirements" of modern commercial aircraft.

He added: "The engine has a Boom-designed axisymmetric supersonic intake, and a variable-geometry low-noise exhaust nozzle that efficiently combines the hot exhaust air with the cooler bypass air and varies the exhaust area to match subsonic and supersonic thrust requirements," and that should allow for takeoffs that do not create an airport noise problem.

For Boom, it's the boom that could emerge as the biggest hurdle. Without the ban being lifted, Overture could have difficulty gaining as much traction as Boom would like. Routes such as New York to Los Angeles would be off the table, and routes such as Chicago to Amsterdam would require the aircraft to fly at subsonic speeds for the parts of the journey that are over land.

While less than ideal, that's the scenario the company is planning for. "When flying over land, Overture will fly at a high subsonic speed that is about 20% faster than current commercial aircraft" without producing a sonic boom, Follak said.

Even with these limitations, Boom is projecting it can sell 1,000 to 2,000 Overtures to airlines, which means many more routes than the limited trans-Atlantic Concorde lineup operated by British Airways and Air France. "In total, there are more than 600 mostly trans-oceanic routes on which Overture offers a compelling speedup without changes to today's overland flight regulations," Follak said. "What I can tell you is that we expect that North America to/from Europe will see robust demand for Overture flights." He added that the company also sees trans-Pacific opportunities and potential routes between the Middle East and Asia.

Boom has also promoted the possibility of a "same day" trans-Atlantic trip, in which a New York businessperson returns from London following a midday meeting and, with the time change, is able to sleep at home that night.

But in the long term, data gathered from the X-59 flights "hopefully paves the way for the FAA loosening some restrictions on overflight of land," Combs says.

One conviction is widely shared: A new supersonic jet would be vastly different from the Concorde, though this is no guarantee the aircraft will be commercially viable.

"The Concorde was developed in the 1960s, and we're now in 2023," Tie of Exosonic says. "There's been a lot of advancement. And so I think there are some general industry-wide savings you'll get in terms of performance and cost and weight" that wouldn't have been possible with the Concorde.

Despite the hurdles, Combs believes a new era of supersonic flight will happen. "I think there's enough momentum that I'm very confident we will see supersonic passenger flights in the future," he says. "When that happens, and who it is, that I'm not as confident about." ★

▲ British Airways conducted the last passenger flight with a Concorde in October 2003, but the design's final flight occurred a month later when British Airways flew 100 employees from London Heathrow Airport to Bristol Filton Airport. The airliners each required four Rolls-Royce/Snecma Olympus 593 engines augmented with afterburners to reach their cruising speed of Mach 2.

Adrian Pingstone

So you think you know lift?

Better read this

Given how deeply air transportation is woven into modern life, it's surprising that the precise workings of aerodynamic lift remain a topic of debate among the experts. Matters get even murkier for those of us on the periphery, where misconceptions can percolate. To sort all this out, I met on a video call last month with two experts, Paul Bevilaqua, retired from Lockheed Martin Skunk Works, and Haithem Taha of the University of California, Irvine. I learned about several myths and at least one collapsing theory. Here is our discussion, lightly edited and compressed. – *Ben Iannotta*

Ben Iannotta: I know I'm not the only one who's looked out an airplane window and marveled at the power of aerodynamic lift. A 787-8 weighs about 230,000 kilograms. That's the equivalent of 38 African bull elephants. And yet, most of us have no fear of getting on an aircraft of that size, and, in fact, maybe those are the among the safest out there. So let's learn more about lift from two experts. First, Paul Bevilaqua is a former chief engineer of Lockheed Martin Skunk Works in California. Paul, what projects were underway during your tenure?

Paul Bevilaqua: I played a leading role in developing the Joint Strike Fighter. The Marines asked me if I could come up with something to replace both the subsonic Harrier and the supersonic F-18, and so I invented the propulsion system that gives the supersonic F-35B vertical capabilities. I also realized you could take that propulsion system out and develop Navy and Air Force variants of the same airplane.

Iannotta: Next, Haithem Taha is an associate professor of mechanical and aerospace engineering at University of California, Irvine. Haithem, you and a student published a paper, "A Variational Theory of Lift." I've heard that maybe the textbooks now need to be rewritten.

Haithem Taha: Well, I received a few congratulating comments from some colleagues all over the world, and at least some of them plan to add 10 minutes in their class on the Kutta condition about this theory.

Iannotta: You're from Egypt. How did you come over here to UC Irvine?

Taha: I did my Ph.D. at Virginia Tech, and it was in engineering mechanics on flapping flight, simultaneously with a master's degree in mathematics. Then I searched in the job market and became lucky to come to UC Irvine.

Iannotta: Let's get into it. I thought aircraft generate lift because the air pressure over the wing is less than under it. Is that much correct?

Bevilaqua: It's partially correct. There are several aspects of lift, and different people have different views. Some people say an airfoil is shaped to develop a pressure difference. That's the action, and the reaction is a downwash behind the wing that satisfies Newton's law of action and reaction. Other people say the airfoil is shaped to push the air down behind the wing. That's the action, and the reaction is a lift on the wing. But both those ideas are wrong.

What we're dealing with is something like the Hindu parable about the blind men and the elephant. An elephant comes to town, and the blind men have no experience with an elephant. So one of them grabs the trunk and says, "Aha! An elephant's like a snake." Another one grabs a leg and says, "Aha! An elephant's like a tree." Another one grabs the tail and says, "Aha! It's like a rope" and the last one says, "No, no" — he grabs the tusk — "it's like a spear." And that's what we're dealing with when it comes to lift. In one version of the parable, they end up fighting each other, beating each other with their canes. In another version, they sit down and listen to each other and put together a complete picture by collaborating. And I hope that's what we're going to do.

There's a beach in St. Martin in the Caribbean, where I was vacationing several years ago, where you can stand at the end of the international airport runway. The airplanes are coming in for a landing a hundred feet above you, but there was no huge downwash. I'm thinking, "Well, wait a minute. How does this really work?"

Iannotta: Haithem, does your variational theory of lift address this downwash question?
Taha: The theory confirms what Paul was saying. The theory is more to complement the picture that Kutta has formulated rather than to challenge the Kutta theory itself. For the lack of better words, Kutta's theory becomes a special case of the new theory. There is no contradiction, really.

Iannotta: You're talking about Martin Kutta, the German mathematician from the early 1900s.
Taha: 1902, yes, his famous paper.

Iannotta: To what degree is the Kutta condition a complete explanation, and to what degree is the Kutta condition incomplete?
Bevilaqua: I think it is complete. In one view, it's the boundary layer viscosity that adds up and prevents the flow from going around the trailing edge. Another view is that it requires an infinite velocity to go around a sharp trailing edge, and because the flow is inviscid [meaning there is no viscosity], viscosity doesn't have anything to do with it.
Taha: On the Kutta condition, I'd like to address the completeness versus incompleteness. Yes, it is indeed the dominant theory of lift that is being taught in every single aeronautical engineering school throughout the world and discussed in every single textbook in aerodynamics.

Iannotta: Briefly explain what the Kutta condition is.
Taha: If we have a regular wing shape, there are several possibilities for how the air flows over. It could rotate around the trailing edge from the lower surface to the upper surface, or vice versa. The flows could come smoothly together off the trailing edge, and there is no flow from the lower surface to the upper surface or vice versa. The Kutta condition simply states that this is the case in reality: There is no flow from the lower surface to the upper surface, or vice versa. But luckily, our undergraduate students do not ask the following question: What happens if we don't have a sharp edge? The dominant theory that we teach all over the world — it immediately collapses.

There is no theoretical model nor a physical explanation now that can give you how much lift is generated if we don't have a sharp trailing edge, or if we have multiple sharp edges or if an airfoil with a single sharp edge is doing an unsteady maneuver, like in the "Top Gun" movie by Tom Cruise. We already know in this case that during the transient period before reaching steady state, the flow goes from around the edge from the lower surface to the upper surface — so the Kutta condition will not apply. So, it's quite bothering that the dominant theory that we teach all over is quite fragile.

Iannotta: Are there aircraft flying today that have non-sharp trailing edges or multiple sharp trailing edges?
Bevilaqua: There are supersonic airfoils that have sharp leading and trailing edges, and so does the airfoil on the F-117. In fact, what we say in aerodynamics is that you can make a barn door fly if you have enough thrust in your engine. The purpose of shaping the airfoil is to get lift efficiently.

Iannotta: Haithem, can you take apart the Hertz principle of least curvature discussed in your theory for us?
Taha: It's actually very simple and intuitive: If we have

a free particle, it moves along a straight line. But if you add a constraint on the particle, it will deviate from a straight line. So Hertz's principle asserts that the particle will deviate from the straight line only by the amount to satisfy the constraint. Nature will not overdo it because the deviation from a straight line is curvature, hence the name "least curvature." So if I have a particle moving anywhere, it will always try to minimize its curvature. If I have a collection of particles together moving in a system, they minimize the curvature of the entire system. You place a wing in their way, so now you have forced them to flow around. The only option that will minimize the total curvature of the system is that they come smoothly together from the trailing edge, matching the Kutta condition. So this is how we find the circulation on any smooth shape without sharp edges. We simply minimize the total curvature with respect to circulation.

Iannotta: You mentioned the idea of air from the bottom circulating around the trailing edge.
Taha: I'm saying nature will prevent that. Engineers always like to ask why. "Why is there lift?" Because there is pressure difference. "Why is there pressure difference?" Because there is velocity difference. "Why is there velocity difference?" Because there is circulation. "Why is there circulation?" Well, the answer has always been "Because of the Kutta condition." But the Kutta condition did not come from first principles. We stop asking why only when we encounter first principles. So now we are saying, "No, there is circulation because that is the minimum curvature solution, and the minimum curvature is a first principle."
Bevilaqua: I would like to add that the variational principle is really also another way of stating Newton's law of inertia. The body moving in a straight line will keep moving in a straight line. So you've got these flows coming along the top and bottom of the surface, moving along the surface. They want to keep doing that, and the flow will make an adjustment to preserve that motion. It's the same principle, really.

Iannotta: Am I correct that it's a myth that the air crossing beneath the wing and over the wing must come together at the same time?
Taha: It's a myth. Nature is not that kind to keep people who are together, together forever.
Bevilaqua: Well, I don't know where it came from. It's a simple explanation that satisfies most people. They go away, and they stop bothering you.

Iannotta: In reality, the air is going faster over the top of the wing, and it gets past the trailing edge sooner than the air underneath.
Taha: Yeah.
Bevilaqua: The circulation actually is an exponential decay as you move away from the airfoil. So when you get far upstream and far downstream, the velocities do come back together. It's just locally where the airfoil is that you have the difference. But far downstream they do come together.

Iannotta: I'm picturing a rock in a river.
Bevilaqua: Right. After a while, the flow forgets there was a rock. You get back to uniform flow.

Iannotta: Let's say there's an airfoil, and above it we know the pressure is less than below it. So there's nothing above the wing to restrain it. The air beneath the wing naturally pushes it upward, and that's lift. Have I offended reality?
Bevilaqua: The whole thing is the circulation around the wing. The air is going faster above and slower below it, so the pressure is lower above and higher below.

Iannotta: And that's Bernoulli's principle.
Bevilaqua: Yeah. And if you look upstream and downstream, the air in front is going up, and the air in back is going down. And so, if you look at a momentum change, there's Newton's second law of motion: The mass of air is accelerated downward, but there is no net downwash. You're changing the up velocity to a down velocity. So, the whole thing is happening together all at once — the pressure force and momentum change. The elephant is the circulation.

Iannotta: We know from Bernoulli's principle that pressure goes down when a fluid flows faster; that's why the pressure over the wing is less. It's not like there's some gap there, correct?
Bevilaqua: Right. The wing is sucked up from the top and pushed up from the bottom.

Iannotta: I see. Haithem, you talk about viscosity in your paper.
Taha: I belong to the camp that believes viscosity is not essential to generating lift. There is a governing equation that is Euler's [Swiss mathematician Leonhard Euler]. If you solve the Euler equation over an airfoil, it's not unique. It has infinitely many solutions. It has a solution with zero lift. This doesn't happen when you solve the Navier-Stokes equation with the friction term, which immediately gives many people the impression that viscosity is essential.
Bevilaqua: You said that the Euler equations do not develop lift, but Pradeep Raj [a professor at Virginia Tech] showed that they do.
Taha: Yes, I believe that Dr. Raj solved the compressible Euler equation and computed the lift. Even without invoking the Kutta condition, he found Kutta's lift. However, he solved it using computational fluid dynamics by a numerical algorithm. Well, any numerical algorithm has some dissipation in it, and he argued that this numerical dissipation plays the

PAUL BEVILAQUA
retired as chief engineer of Lockheed Martin Skunk Works in 2011. He holds a doctorate in aeronautics and astronautics from Purdue University.

HAITHEM TAHA
is an associate professor of mechanical and aerospace engineering at the University of California, Irvine. He has a doctorate in engineering science and mechanics from Virginia Tech.

role of an artificial viscosity. So that's one explanation. But in our theory, there is no numerical scheme. There is no artificial viscosity, and we recover the Kutta condition, anyway. This is one of the strengths of our theory. Thanks, Paul, for reminding me of this point.
Bevilaqua: I think that's the brilliant part of your contribution. It's inertia, not viscosity, that enforces the Kutta condition and creates lift.

Iannotta: If engineers understood all this perfectly, could they make a better aircraft?
Bevilaqua: They wouldn't make such a bad one. New hires often come in with a wrong conception. You have to explain to them: "Well, that's not where lift comes from." I have had engineers suggest blowing a jet over the top of the wing, "Because the air goes faster — that should produce lift." No, that's not going to produce lift, because the thickness of the jet is tiny compared to the huge atmosphere. Therefore, the pressure in the jet is the same as the atmospheric pressure. In fact, Einstein had a wrong idea about pressure. He thought that if you put up a huge hump on top of the wing, the hump would squeeze the air together and cause it to lower the pressure. So it makes it less of a hassle to design airplanes if people understand where the lift comes from.

Iannotta: Could someone make a better paper airplane if I knew the theory?
Bevilaqua: That's a good question. The Wright brothers put thin wings on each side of a bicycle wheel and then rode it through the streets of Dayton. The wing that was pulled back had more drag. They also built a wind tunnel, and they tested little models of thin wings in there. And to his death in 1948, Orville Wright believed that a thin wing was the right way to go. Well, it is the right answer for a paper airplane or a model airplane. It's the wrong answer for a large airplane. A breakthrough came in the 1920s when Clark came up with the Clark Y thick airfoil, and the Wright brothers both said, "That's wrong. We have data that shows a thin airfoil is better." But yes, it is better in a small wind tunnel or on a bicycle wheel balance.

Iannotta: We've been talking about wings with a curve on the upper surface, and probably asymmetrical. So how does a paper airplane fly?
Bevilaqua: Because a thin wing is optimal for very small airplanes. You put it at a large enough angle of attack, and you can get lift out of it even though it's not shaped or cambered or thick or anything.

Iannotta: To close things out, I wanted to give each of you a chance to kind of wrap things up.
Taha: Back to your question about having a good theory. The Wright brothers flew something in 1903, but for 59 seconds. They were knowledgeable because they did an immense amount of tests. Without a theory, you can build a prototype and you can fly it for 59 seconds. You can push here and there and fly it for a few minutes. But to reach the level of maturity that we have nowadays, with millions of flight hours per year, this needs a good theory. And to go to the next phase, it needs an even better theory. So it's just a one step along the right direction.

Iannotta: Paul, how would you wrap things up?
Bevilaqua: It's circulation that creates the pressure difference between the top and bottom of the wing, and the momentum change between upstream and downstream of the wing. In a sense, an airfoil lifts itself by its own bootstraps. It's just different aspects of the same phenomenon. And let me add something we have only touched on, which is the effect of a finite span wing. There is a downwash behind the wing that comes from the vortices that trail off the wing tips. They are the continuation of the circulation around the wing. So people say "Ah! $F = ma$. The downwash must be the reaction to the lift on the wing." But it's not, because the vortices induce an upwash outside of the wing, and there's no net downward flow of momentum. It is not the Newtonian reaction to lift.

Iannotta: So another myth to bust. Thank you both. I think we all have more to think about when we get on our next airplane flight. ★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Calendar

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2023			
30 Jan–2 Feb	Space Mission Operations Course	ONLINE (learning.aiaa.org)	
7 Feb–2 Mar	AI for Air Traffic Safety Enhancement Course	ONLINE (learning.aiaa.org)	
15–24 Feb	Complex Systems Competency Course	ONLINE (learning.aiaa.org)	
21 Feb–2 Mar	Technical Writing Essentials for Engineers	ONLINE (learning.aiaa.org)	
28 Feb–30 Mar	Electric VTOL Aircraft Design: Theory and Practice Course	ONLINE (learning.aiaa.org)	
4–11 Mar*	IEEE Aerospace Conference	Big Sky, MT (www.aeroconf.org)	
6 Mar–12 Apr	Design of Space Launch Vehicles Course	ONLINE (learning.aiaa.org)	
13 Mar–5 Apr	Agile Systems Engineering Course	ONLINE (learning.aiaa.org)	
21 Mar–20 Apr	Design of Modern Aircraft Structures Course	ONLINE (learning.aiaa.org)	
24–25 Mar	AIAA Region III Student Conference	Dayton, OH	3 Feb 23
25–26 Mar	AIAA Region VI Student Conference	Davis, CA	5 Feb 23
27–28 Mar	AIAA Region II Student Conference	Knoxville, TN	27 Jan 23
28 Mar–6 Apr	Introduction to Propellant Gauging Course	ONLINE (learning.aiaa.org)	
29–30 Mar	ASCENDxTexas	Houston, TX	
31 Mar–1 Apr	AIAA Region I Student Conference	Buffalo, NY	27 Jan 23
31 Mar–1 Apr	AIAA Region IV Student Conference	Las Cruces, NM	31 Jan 23
5–26 Apr	Optimal Control for Unpiloted Aerial Vehicles (UAVs) – Online Guided Short Course	ONLINE (learning.aiaa.org)	
11–13 Apr	AIAA DEFENSE Forum	Laurel, MD	18 Aug 22
11–27 Apr	Overview of Python for Engineering Programming Course	ONLINE (learning.aiaa.org)	
13–16 Apr	AIAA Design/Build/Fly Competition	Tucson, AZ	
14 Apr	Aerospace Survivability Course	Laurel, MD (aiaa.org/defense)	
17 Apr–17 May	Hypersonic Flight Vehicle Design and Performance Analysis Course	ONLINE (learning.aiaa.org)	
19 Apr–9 Jun	Design of Gas Turbine Engines: From Concept to Details Course	ONLINE (learning.aiaa.org)	
19 Apr–12 May	Electrochemical Energy Systems for Electrified Aircraft Propulsion 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
2023			
21–22 Apr	AIAA Region V Student Conference	Kansas City, MO	11 Feb 23
25 Apr–11 May	Understanding Aircraft Noise: From Fundamentals to Design Impacts & Simulations Course	ONLINE (learning.aiaa.org)	
25–26 Apr	OpenFOAM® CFD Foundations Course	ONLINE (learning.aiaa.org)	
2–11 May	Digital Engineering Fundamentals Course	ONLINE (learning.aiaa.org)	
8, 15 May	Essential Model-Based Systems Engineering Course	ONLINE (learning.aiaa.org)	
9–11 May	Launch Vehicle Coupled Loads Analysis: Theory and Approaches Course	ONLINE (learning.aiaa.org)	
16 May–8 Jun	Introduction to Aeroelasticity: From Basics to Application Course	ONLINE (learning.aiaa.org)	
16–17 May	OpenFOAM® External Aerodynamics Course	ONLINE (learning.aiaa.org)	
16–25 May	Aircraft Reliability & Reliability Centered Maintenance Course	ONLINE (learning.aiaa.org)	
18 May	AIAA Awards Gala	Washington, DC (aiaa.org/gala)	
22–25 May	Understanding Space: An Introduction to Astronautics & Space Systems Engineering Course	ONLINE (learning.aiaa.org)	
23 May–6 Jun	Sustainable Aviation Course	ONLINE (learning.aiaa.org)	
28 May–1 Jun	25th AIAA International Space Planes and Hypersonic Systems and Technologies Conference	Bengaluru, Karnataka, India	6 Dec 22
6 Jun	OpenFOAM® Aeroacoustics Modeling Course	ONLINE (learning.aiaa.org)	
7 Jun	OpenFOAM® Dynamic Mesh Modeling Course	ONLINE (learning.aiaa.org)	
7–9 Jun*	10th International Conference on Recent Advances in Air and Space Technologies (RAST 2023)	Istanbul, Turkey	20 Mar 23
12–16 Jun	AIAA AVIATION Forum	San Diego, CA	10 Nov 22
19–23 Jun*	International Conference on Icing of Aircraft, Engines, and Structures 2023	Vienna, Austria (https://www.sae.org/attend/icing)	
20–23 Jun	Safety Management Systems in Aviation Course	ONLINE (learning.aiaa.org)	
27–30 Jun*	ICNPAA 2021: Mathematical Problems in Engineering, Aerospace and Sciences	Prague, Czech Republic (icnpaa.com)	
13–17 Aug*	2023 AAS/AIAA Astrodynamics Specialist Conference	Big Sky, MT (https://space-flight.org)	
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

MAKING AN IMPACT International Student Conference

The AIAA International Student Conference took place on 23 January in conjunction with AIAA SciTech Forum. Students who won first place at one of the 2022 AIAA Regional Student Conferences presented their papers at this professional technical conference, which offers students a chance to showcase their original research at an event where they can also network with potential employers and colleagues. The winners were announced at an awards breakfast on 24 January, where JD McFarlan, Vice President and Chief Engineer, ADP, Lockheed Martin, provided the keynote address to the student attendees.

Papers were judged by volunteer professional members with years of experience in the industry. The following papers were declared winners and awards were presented by AIAA Foundation Chair Basil Hassan.


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Undergraduate Category

"Experimental Verification of the USAFA 1-DOF Dynamic Stability Characterization Capability and Future 3-DOF Cross Coupling Enhancements" by Molly Ellinger, Jacob Szymanski, and Casey P. Flagley, United States Air Force Academy (Air Force Academy, CO)

Master's Category

"Optimization of Heat Release within a Dual-Mode Ramjet Using Ignition Delay Energy Source Terms" by Francis A. Centlivre, Wright State University (Dayton, OH)

Team Category

"Design of Large-Scale 3D Printed Components for UAV Cargo Transport" (presented to Cody Watson) by Cody Watson, Caroline Dixon, Nathan Kuczun, and Jade Morton, University of Colorado Boulder (Boulder, CO)

AIAA thanks Lockheed Martin for its generous support of the International Student Conference Program.

Dates for the 2023 Regional Student Conferences can be found on **pages 50–51**. For more information about the student conferences, contact Lindsay Mitchell at lindsaym@aiaa.org, or 703.264.7502.

1 JD McFarlan (right) with Michael Lagana, Manager, University Programs, AIAA.

2 Undergraduate Category winners.

3 Master's Category winner.

4 Team Category winners, represented by Cody Watson.

5 Rudy Al Ahmar (right), Auburn University, winner of the Abe M. Zarem Graduate Student Award for Distinguished Achievement in Aeronautics. with AIAA Foundation Chair Basil Hassan (center) and Faculty Advisor Joseph Majdalani (left).

6 Joseph Day (right), University of Colorado Colorado Springs, winner of the Abe M. Zarem Graduate Student Award for Distinguished Achievement in Astronautics, with AIAA Foundation Chair Basil Hassan (center) and Faculty Advisor Matt Quinlan (left).

Diversity Scholars at AIAA SciTech Forum

Thirteen AIAA Diversity Scholars attended AIAA SciTech Forum, 23-27 January 2022. The AIAA Diversity Scholarship was created to provide networking and engagement opportunities at forums to students from backgrounds that are traditionally underrepresented in the industry. These students receive round-trip airfare, a complimentary hotel stay, forum registration, and additional targeted programming that may help them succeed in the aerospace industry. They also receive a complimentary student membership.

This program is a collaboration of the AIAA Foundation and Boeing. Scholars attended the plenary, Forum 360 sessions, and the student awards breakfast, as well as the Rising Leaders in Aerospace events and other special sessions targeted specifically for the scholars.

Diversity scholarships will be offered at the upcoming AIAA AVIATION Forum and 2023 ASCEND event. AIAA welcomes applications from students in all disciplines with an interest in aerospace, including but not limited to STEM fields, communications, law, industrial design, journalism, and political science. Please visit **aiaa.org/diversityscholars** for more information.

AIAA Foundation Day of Giving

The results are in and together we raised $66,400! Thank you to everyone who participated in the first-ever AIAA Foundation Day of Giving. This incredible campaign honored the past on the anniversary of the Wright Brothers' first flight while looking toward the future. Our members are enabling programs through the AIAA Foundation that will open doors for bright young minds as we prepare them to shape the future of aerospace. If you haven't had the opportunity to contribute, donate to the AIAA Foundation today! **aiaa.org/foundation**

Mark Drela Appointed Editor-in-Chief of AIAA's *Journal of Aircraft*

AIAA has selected **Mark Drela**, Terry J. Kohler Professor of Fluid Dynamics in the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology, as its new Editor-in-Chief for the *Journal of Aircraft (JA)*. He succeeds Eli Livne, the Boeing Endowed Professor of Aeronautics and Astronautics at the University of Washington, who has served as the fifth Editor-in-Chief for *JA* since 2011. Drela, the sixth editor-in-chief for *JA*, will begin this new role in January 2023.

The AIAA Publications Committee oversees the search and selection effort for new editors-in-chief. This year's search committee was led by Jacqueline A. O'Connor, Pennsylvania State University, Publications Committee member. Drela was chosen from among a group of highly qualified candidates.

"The fields of aircraft engineering and aeronautics in general are vital to the global transportation system, to national defense, and to the international economy, and their importance is only growing. The *Journal of Aircraft* is a valuable venue for advancing engineering knowledge, tools, and methods that are critical to developing new aeronautical concepts, vehicles, and systems to further the field. It is an honor to have been selected as its new Editor-in-Chief." said Drela.

Drela, an AIAA Fellow and NAE member, holds a Master of Science in Aeronautics and Astronautics and a Ph.D. in Computational Fluid Dynamics in the Department of Aeronautics and Astronautics with a Minor in Applied Mathematics and Structures from MIT. Some of his recent awards and honors include the 2022 ASME IGTI Turbomachinery Committee Best Paper Award, the 2018 AIAA Reed Aeronautics Award, and the 2017 AIAA Theoretical Fluids Best Paper. Drela's research interests consist of aerodynamics, computational fluid dynamics, design methodology, computation-based design, and low-order modeling of aeromechanical systems.

The *Journal of Aircraft* is devoted to the advancement of the applied science and technology of airborne flight through the dissemination of original archival papers describing significant advances in aircraft, the operation of aircraft, and applications of aircraft technology to other fields.

Craig R. Wanke Appointed Editor-in-Chief of AIAA's *Journal of Air Transportation*

AIAA has selected **Craig R. Wanke**, Chief Engineer for MITRE's Center for Advanced Aviation System Development (CAASD), and an AIAA Associate Fellow, as its new editor-in-chief for the *Journal of Air Transportation (JAT)*. He succeeds Karl Bilimoria, an aerospace engineer at NASA Ames Research Center, who has served as the first editor-in-chief for *JAT* since 2016. The journal was originally published as the *Air Traffic Control Quarterly* by the Air Traffic Control Association (ATCA) between January 1993 and December 2015. Wanke will begin this new role as *JAT*'s second editor-in-chief in January 2023.

The AIAA Publications Committee oversees the search and selection effort for new editors-in-chief. This year's search committee was led by Jacqueline A. O'Connor, Pennsylvania State University, Publications Committee member. Wanke was chosen from among a group of highly qualified candidates.

"Air Traffic Management (ATM) is in a period of rapid evolution, driven by innovations in new vehicles and new missions, advances in artificial intelligence, and the challenge of sustainability in a changing climate. *JAT* is a critical source for peer-reviewed, leading-edge ATM innovation, and it is a great honor to have been chosen as the editor in this exciting time," said Wanke.

Wanke holds a Master of Science and Ph.D. in Aeronautics and Astronautics from the Massachusetts Institute of Technology. Some of his accomplishments include leading the development, field testing, and technology transfer of several capabilities now deployed as part of the FAA's operational traffic flow management system (TFMS). Wanke has served as Principal Investigator for many years on MITRE IR&D projects, and in addition to serving as the Chief Engineer of CAASD, he also currently leads the MITRE IR&D program in aviation and surface transportation. He was an Associate Editor of *JAT* from 2016 to 2022, and he also has authored or co-authored more than 100 journal and conference papers on air traffic management and various aeronautical engineering topics.

JAT is devoted to the dissemination of original archival papers describing new developments in air traffic management and aviation operations of all flight vehicles, including unmanned aerial vehicles (UAVs) and space vehicles, operating in the global airspace system.

Diversity Corner

CREDIT: NICK MINTZ

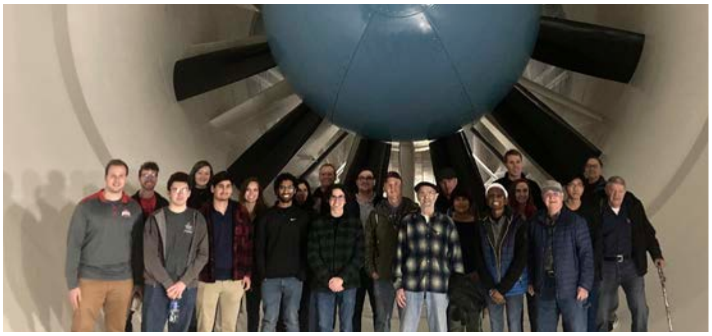
NAME: Solteria Ross

NOTABLE CONTRIBUTIONS:
Ross is a Systems Engineer within Lockheed Martin's Deep Space Exploration Advanced Programs. She holds a B.S. in Aerospace Engineering with minors in English and Women's, Gender and Sexuality Studies from North Carolina State University, Cum Laude.

POTENTIAL SOCIETAL IMPACT OF CONTRIBUTIONS:
A first-generation college student, a Brooke Owens Fellowship winner, and one of our 2022 AIAA SciTech Forum Diversity Scholars, Ross is a leader and a champion of diversity in STEM. While at NC State, she mentored first-year engineering students and performed K-12 STEM outreach. She co-led a Diversity Team initiative within the College of Engineering to help recruit and retain engineering ambassadors from underrepresented backgrounds with a mission to represent all forms of diversity. She has previously interned at Collins Aerospace, GE Aviation, and Redwire Space.

Ross is passionate about the intersection of aerospace and Women's and Gender Studies. Her research has explored the gender studies framework as a more egalitarian approach to human activity in space.

*In collaboration with the AIAA Diversity and Inclusion Working Group and Claudine Phaire, SAT OC is highlighting prominent members of the wider aerospace community in the Diversity Corner.



Dayton-Cincinnati Section Has Opportunity to Tour HALO Wind Tunnel

In December members from the AIAA Dayton Cincinnati Section were hosted at Honda Labs Ohio-Wind Tunnel (HALO_WT) by Mike Unger, Facility Lead, and Tom Ramsay, Technical Lead. The members toured the new full-scale wind tunnel and learned about the technical and practical usage aspects of this new facility that supports Honda's automotive aerodynamic, aeroacoustics, and racing development.

SAT OC – New Collaborations

By: Amir S. Gohardani, SAT OC Chair

In a recent committee meeting of the AIAA Society and Aerospace Technology Outreach Committee (SAT OC), the topic of collaboration stood out as a recurring theme. With so many cross-disciplinary subjects impacting the aerospace sector, understanding the confluence of these topics is of the essence. Collaboration also facilitates a profound understanding of identifying discord or synergy. Therefore, initiating collaboration with other outreach committees, technical committees, and working groups across AIAA is a top-line item in SAT OC's priority list. Based on SAT OC's membership in 2023, there are many exciting opportunities for exploring multidisciplinary topics within the committee.

SAT OC promotes the transfer of aerospace technology and techniques to help solve critical problems in society, and improve the general quality of life. The committee focuses on how aerospace technology and techniques help solve critical societal challenges and improve the quality of life, and seeks to understand the interactions between the aerospace enterprise and broader social and cultural trends. The core strength of the committee stems from bringing together distinguished AIAA members whose professions, studies, and interests include enhancing the interaction between the aerospace industry and society.

As part of SAT OC's efforts, an initiative is underway to collaborate with the American Astronautical Society's *Space Talk* and *Space Times* by seeking to bring attention to salient issues in space policy, future space exploration, and notes of interest to both the professional and the general community of space flight advocates.

On Tuesday, 24 January, AIAA held a Meet and Greet event at AIAA SciTech Forum so members could congratulate our newest Associate Fellows. These members were recognized for their outstanding accomplishments in engineering or scientific work, outstanding merit, and contributions to the art, science, or technology of aeronautics and astronautics.

Nominate Your Peers and Colleagues!

Do you know someone who has made notable contributions to aerospace arts, sciences, or technology? Bolster the reputation and respect of an outstanding peer throughout the industry.

Nominate them now!

Candidates for SENIOR MEMBER

- Accepting online nominations monthly

Candidates for ASSOCIATE FELLOW

- Acceptance period begins 1 February 2023
- Nomination forms are due 15 April 2023
- Reference forms are due 15 May 2023

Candidates for FELLOW

- Acceptance period begins 1 April 2023
- Nomination forms are due 15 June 2023
- Reference forms are due 15 July 2023

Candidates for HONORARY FELLOW

- Acceptance period begins 1 February 2023
- Nomination forms are due 15 June 2023
- Reference forms are due 15 July 2023

Criteria for nomination and additional details can be found at
aiaa.org/Honors

AIAA
SHAPING THE FUTURE OF AEROSPACE

Public Policy News of Relevance to the Aerospace Community

The 118th Congress officially begun their session on 3 January 2023. After the 2022 midterm elections, Democrats kept their majority and gained one seat in the U.S. Senate, but Republicans won a majority in the U.S. House of Representatives.

In the Senate, Sen. Chuck Schumer (D-NY) remains as the Senate Majority Leader and Sen. Mitch McConnell (R-KY) remains as the Senate Minority Leader. In the Senate Committee on Appropriations, there is new leadership. After long service, Sens. Patrick Leahy (D-VT) and Richard Shelby (R-AL) both retired. Replacing them are Sen. Patty Murray (D-WA) as the Chair and Sen. Susan Collins (R-ME) as the Ranking Member. For the Senate Commerce, Science, and Transportation Committee, Sen. Maria Cantwell (D-WA) remains Chair, and Sen. Ted Cruz (R-TX) is the new Ranking Member, replacing Sen. Roger Wicker (R-MS) who is now Ranking Member of the Senate Committee on Armed Services. In the Senate Committee on Energy and Natural Resources, Sen. Joe Manchin (D-WV) remains the Chair and Sen. John Barrasso (R-WY) remains the Ranking Member.

In the House of Representatives, new leadership has been elected for both sides. Rep. Kevin McCarthy (R-CA) was elected as the 55th Speaker of the House. Reps. Steve Scalise (R-LA) and Tom Emmer (R-MN) were elected as Majority Leader and Majority Whip. For the Democrats, Rep. Hakeem Jeffries (D-NY) was elected House Minority Leader, replacing Rep. Nancy Pelosi (D-CA), while Rep. Katherine Clark (D-MA) was elected as the House Minority Whip, replacing Rep. Steny Hoyer (D-MD). In the House Appropriations Committee, Rep. Kay Granger (R-TX) is the new Chair and Rep. Rosa DeLauro (D-CT) is the Ranking Member. In the House Energy and Commerce Committee, Rep. Cathy McMorris Rodgers (R-WA) is the new Chair and Rep. Frank Pallone (D-NJ) is the new Ranking Member. In the House Committee on Science, Space, and Technology, Rep. Frank Lucas (R-OK) is the new Chair and Rep. Zoe Lofgren (D-CA) is the new Ranking Member. Lastly, in the House Transportation and Infrastructure Committee, Rep. Sam Graves (R-MO) is the new Chair and Rep. Rick Larsen (D-WA) is the Ranking Member.

Obituaries

AIAA Associate Fellow Soderberg Died in January 2022

Laurence "Larry" R. Soderberg, 95, died on 16 January 2022.

Soderberg's interest in aviation began when he worked summers at Casper Army Airbase, a center for training World War II pilots. In July 1943 he was accepted for the now famous Navy V-12 program that educated and trained 30,000 naval officers at 120 colleges and universities in a crash nonstop 32-month program. Soderberg was sent to the University of Minnesota, graduating with a Bachelor of Aeronautical Engineering Degree with Honors, and led the V-12 Batalion as Sub-Commander.

Soderberg was assigned to the Canal Zone, maintaining and flying Martin PBM-5 flying boats, searching for residual U-boats along North and South America. Retiring from active duty in June 1946, he remained as an active Navy Reserve through Korea and Vietnam, retiring as Lieutenant Commander in 1986.

Furthering his studies at Ohio State University and the University of Colorado Boulder, Soderberg earned a Master of Science in Aeronautical Engineering in 1947, before becoming an instructor in Mechanical Engineering at the University of Wyoming. He also worked at the NACA Ames Laboratory, the Denver Research Institute at the University of Denver, and Beech Aircraft in Boulder.

In 1960, Soderberg was employed by Martin Company (now Lockheed Martin), which held contracts to build the Titan intercontinental ballistic missiles. During his 28 years there, he worked on a variety of programs such as the Space Shuttle; Titans I, II, III; independent research and development; propulsion research; a highly classified Navy satellite; and war gaming against the Soviets. He retired at the Director level from Martin Marietta Aerospace in 1988. He held four U.S. patents that he contrived to solve certain challenging aerospace design problems.

Soderberg ran his own consulting company called Systems Analysis Inc. from 1989 to 1993 and performed highly classified work for the National Academy of Science, Office of Naval Intelligence, and Martin Marietta. He was a Registered Professional Engineer (Ret.) in Colorado and Minnesota.

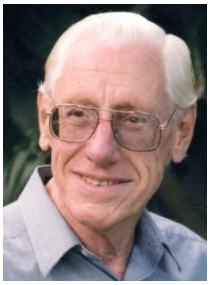
AIAA Associate Fellow Dittberner Died in November

Gerald J. Dittberner, 81, renowned climatologist, satellite meteorologist, forecaster, and engineer, died on 22 November 2022.

Dittberner earned his Bachelor's degree in Electrical Engineering from the University of Minnesota (1964); M.S. degree in Meteorology, Space Science & Engineering from the University of Wisconsin (1969), and his Ph.D. in Meteorology from the University of Wisconsin (1977). An early global warming researcher in the 1970s, Dittberner served in the U.S. Air Force for 21 years, starting with the Defense Meteorological Satellite Program's satellite operations and applications. His final posting was as the program manager, Office of Scientific Research at Bolling Air Force Base (1984–1985)

Following retirement from the Air Force as a Lieutenant Colonel, Dittberner worked with research satellites in the aerospace industry for 10 years, including as a Geostationary Operational Environmental Satellites (GOES) program manager and advanced technology research and development manager for 12 years with NOAA.

Dittberner was a member of AIAA for over 35 years. He was a member of the AIAA Space Operations and Support Technical Committee from 1989 to 1994.



AIAA Senior Member Bradley Died in December

Robert (Bob) Bradley, age 94, died on 2 December 2022.

Bradley was raised around aviation as his father worked for Transcontinental Air Transport (TAT), the forerunner of TWA, and served as Charles Lindbergh's flight mechanic when Lindbergh flew the initial transcontinental survey flight for TAT.

Bradley enlisted in the U.S. Army Air Force in 1945, and served in the Communication Service. After leaving the Air Force, he attended the University of Southern California where he graduated in 1953 with a B.Sc. in Physics. He worked for four years at North American Aviation prior to moving in 1957 to Convair Astronautics (later General Dynamics Space Systems Division) where he remained until his retirement in 1993.

He worked initially in Operations Analysis, then in the Technical Information Center, and then the Economic Analysis Group, all in the Advanced Engineering Department. Bradley led or conducted many space and missile cost analyses concerning Atlas and Centaur variants, and many new advanced launch vehicles — Geostationary Platform, the Small ICBM, and the ALS launch vehicle, among others. The group was eventually moved from Engineering into the Contracts and Estimating Department where he became Manager of Economic Analysis.

After his retirement in 1993, Bradley became a volunteer archivist at the San Diego Air & Space Museum, specializing in the space and missile collection and its Convair archives. He wrote and published two volumes on *Convair Advanced Designs*. Bradley also served on the AIAA Economics Technical Committee from 1990 to 1994.

AIAA Honorary Fellow Abramson Died in December

Norman Abramson died on 19 December 2022.

Abramson received his B.S. in Mechanical Engineering in 1950 at Stanford University; M.S. in Engineering Mechanics, 1952; Ph.D. at University of Texas, Austin, 1956. He was well known in the field of theoretical and applied mechanics, particularly in aeronautics and astronautics.

Abramson retired as the Executive Vice President of Southwest Research Institute (SwRI) in 1991, at the completion of 35 years of service in increasingly responsible positions. As Executive Vice President, he transformed SwRI's international research program to a vital role in maintaining the Institute's position as one of the leading nonprofit contract R&D organizations in the world. He also oversaw the growth of SwRI to a staff of over 2,500. During this time, Abramson developed a nationally recognized major research and development program in solid and fluid mechanics. His personal contributions to problems of dynamic behavior of liquid propellants in rockets and spacecraft earned him an international reputation. He was internationally known in the field of ship structural analysis and dynamics, as well as an authority in hydroelasticity. Besides serving as the manager or principal investigator of more than a score of significant research projects, he was extensively sought after as a technical consultant and advisor by a large number of governmental agencies and industrial concerns.

Abramson's accomplishments led to many honors, including the ASME Medal, ASME Centennial Silver Medal, and first recipient of the ASME Applied Mechanics Division Award, along with other numerous scientific awards. He was a member of U.S. National Academy of Engineering.

Abramson joined AIAA in 1947. He became a Fellow in 1970 and an Honorary Fellow in 2018. He was recognized with the 1973 Distinguished Service Award and the Structures, Structural Dynamics, & Materials Award in 1991.

AIAA Standards Under Revision

The following AIAA Standards are under revision: AIAA S-111 (Qualification and Quality Requirements for Space Solar Cells), AIAA S-112 (Qualification and Quality Requirements for Electrical Components on Space Solar Panels) and S-113 (Criteria for Explosive Systems and Devices on Space and Launch Vehicles). If you are interested in any of these revision projects, please contact Nick Tongson (nickt@aiaa.org).

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one was just luck, luck that someday will run out.

Right now, the options for LEO operators are too broad: An object can be left at an altitude that ensures it will reenter within 25 years, and therefore meet the U.N. guidance; an object can be left in a graveyard orbit above LEO, but below geosynchronous Earth orbit, while somehow avoiding the medium-Earth orbital regime populated by the GPS constellation and other navigation satellites; or an object can be moved to a graveyard orbit above GEO.

None of those options is satisfactory. Let's dissect this a bit. When objects reenter naturally, there is a higher chance that some part of their mass will survive the process and reach the surface, potentially in a populated area. That's because the angle of reentry is shallower and the heating rate and dynamic pressure that the object experiences are also less than if forced to reenter with intention and planning. The generally adopted threshold for concern about the risk of human casualty by most space agencies is a 1-in-10,000 chance of someone being killed, formally called the probability of expected casualties. That risk, however small, is unacceptable. We should not accept, as a part of normal space operations and business, expected casualties from reentries if we can control them. We wouldn't build a highway overpass and accept that one in 10,000 drivers will be killed by a piece falling from it. Leaving objects in a graveyard orbit is the equivalent of dumping them into a landfill, but worse. Imagine a landfill of objects that move around in ways that even the most skilled astrodynamicists or advanced software have trouble predicting because of a paucity of measurements and vast number of variables. Objects in graveyard orbits should never fall back to Earth or into the LEO regime, but just like with a landfill, there can be unanticipated consequences. Put simply, we're leaving trash out in the hopes that in the near term it won't risk space operations and activities, but for the long term, who knows?

Because we began launching stuff into space back with Sputnik in 1957 and Explorer 1 in 1958, but did not formally begin addressing the fate of the things we launch until 2001 when the 25-year guideline was published (NASA's 1995 guidelines for mitigating debris from its own missions being an exception), there are many thousands of objects, large ones too, that were abandoned on orbit without a disposal plan. Yes, I used the word abandoned. Counting on Mother Nature to dispose of an object is tantamount to abandoning it. The 25-year guideline and the FCC's five-year rule should be supplemented by one or more laws that require spacecraft and rocket stages to be disposed of responsibly, whether by the operator or by a third party. These objects should be deorbited in a controlled manner, or better yet, brought home or taken to an orbital facility for recycling, because recycling or reuse could be built into the design if we wanted to. Designing satellites and rockets for reuse and recycling is called Extended Producer Responsibility, within waste management processes. Doing so would address the threat to space sustainability, which I define as humanity's ability to utilize orbital space as a finite resource, free and unhindered in perpetuity.

The United States considers itself the leader in space. Establishing proper disposal techniques by law would provide incentives for others around the world to join in creating a thriving, circular economy in space. A circular space economy prioritizes the prevention of pollution through reuse and recyclability, followed by active disposal for those things that can't be reused or recycled. The United States already has a company with recyclable rockets: SpaceX. Bravo! Now we need recyclable and reusable satellites. That's critical, because even with the 25-year guideline and the five-year rule, the debris problem continues to compound.

Therefore, as we begin to recycle and reuse, we also need to shift to active cleanup. It would be nice if there were a list of space objects that all space actors agree should be removed first, based on risk. Today, the best we have is a loose collection of recommendations from the scientific community.

It's time for us to abandon abandonment. ★

LOOKING BACK

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1923

Feb. 5 The U.S. Air Mail Service is awarded the 1922 Collier Trophy for completing a year of transcontinental air mail deliveries without a fatal accident, proving the efficiency and speed of air travel. **Aeronautical Digest**, March 1923, p. 214.

Feb. 15 French aviator Joseph Sadi-Lecointe sets a world speed record of 375 kph. He receives the congratulations of the president of the French Republic. **Air Service News Letter**, March 5, 1923, p. 2.

Also in February U.S. rocket pioneer Robert Goddard experiments with ammonium nitrate as a propellant. His work for the U.S. Navy concludes this month. **The Papers of Robert H. Goddard**, Vol. 1, p. 489.

1948

1 **Feb. 4** The experimental Douglas D-558-2 Skyrocket completes its first phase of test flights at the U.S. Air Force Muroc Desert Test Center in California, with Douglas test pilot John Martin at the controls. Future test aircraft are equipped with both jet and rocket engines, but the aircraft used for the initial flights is powered by a single turbojet. **Aviation Week**, Feb. 23, 1948, p. 8; Richard Hallion, **Supersonic Flight**, p. 151.

Feb. 4 Otto Praeger, "father of the air mail," dies. As second assistant postmaster general, Praeger inaugurated and directed the U.S. Air Mail Service from May 1918 until March 1921. **A Chronology of American Aerospace Events**, p. 54.

Feb. 6 The U.S. Army announces the first successful electronic control of a V-2 rocket in a 110-kilometer ascent at White Sands, New Mexico. **A Chronology of American Aerospace Events**, p. 54.

Feb. 6 Royal Air Force Squadron Leader William Waterton sets a world speed record of 873.68 kph in a Gloster Meteor IV jet. This exceeds the record set by a de Havilland Vampire by 74.06 kph. **The Aeroplane**, Feb. 13, 1948, p. 176.

2 **Feb. 10** Maj. Gen. James Fechet, chief of the U.S. Army Air Corps from 1927 to 1931, dies. He was Gen. Billy Mitchell's replacement after Mitchell's court-martial and removal from the Air Service, though he came to espouse Mitchell's views on the need to "awaken the nation" and build an adequate aerial defense. **Aero Digest**, March 1948, p. 152.

Feb. 12 Robert Kronfeld, one of the world's outstanding glider pilots, is killed when the experimental flying wing glider he is piloting crashes. Born in Austria, he settled in England in 1930. His notable achievements include a two-way flight across the English Channel in 1931. He served as a squadron leader in the Royal Air Force in World War II and afterward joined General Aircraft Ltd. as a test pilot. **Flight**, Feb. 19, 1948, p. 215.

Feb. 25 Pan American Airways inaugurates direct service between the U.S. and South Africa. A Lockheed Martin Constellation named Clipper Southern Cross departs from La Guardia Airport in New York carrying 22 U.S. publishers, newspaper executives and airline officials, and heads for Johannesburg, with stops at the Azores, Dakar, Accra and Leopoldville. **The Aeroplane**, March 5, 1948, p. 288.

Feb. 26-27 A Vickers Supermarine Attacker jet fighter piloted by U.K. Royal Air Force Lt. Cmdr. Michael Lithgow covers a single-circuit course in England in 6 minutes and 39 seconds, setting an international speed record of 902.25 kph (560.634 mph). Not content with this speed, Lithgow makes two further attempts over the same course and reaches a speed of 909.088 kph (564.881 mph). The course runs from Chilbolton to Pepperbox to Ibsley to Sway Tower and back. **The Aeroplane**, March 5, 1948, p. 264.

1973

Feb. 1 This date marks the 10th anniversary of the formation of the U.S. Communications Satellite Corp. The corporation was formed from a mandate in the Communications Satellite Act of 1962, in which Congress directed the establishment of a global comsat system in cooperation with other countries. The company now employs 1,100 people who operate seven U.S. Earth stations, among other facilities. NASA, **Aeronautics and Astronautics, 1973**, p. 35.

Feb. 6 NASA's Marshall Space Flight Center in Alabama announces the establishment of the Large Space Telescope Task Force to direct the planning and preliminary design of a telescope to be launched by the space shuttle in the 1980s. This LST design is to be capable of looking at galaxies 100 times farther away than those seen by the most powerful ground-based telescopes. Later renamed the Hubble Space Telescope, it is launched into low-Earth orbit in 1990 and remains operational. NASA, **Aeronautics and Astronautics, 1973**, p. 39.

Feb. 8 Jacques-Yves Cousteau, the French oceanographer, speaks live from his research vessel in the Antarctic to reporters via the Applications Technology 3 satellite. Cousteau's research includes measurements of chlorophyll, temperatures and water transparency, sending the data to NASA's Ames Research Center in California for comparisons with satellite data. **New York Times**, Feb. 9, 1973, p. 57.

3 **Feb. 8** U.S. President Richard Nixon flies in the new Air Force One plane for the first time. Dubbed the "Spirit of '76," this Boeing 707 replaces the aircraft that began service in 1962. The Spirit of '76 was flight tested by the presidential pilot, U.S. Air Force Col. Ralph D. Albertazzie, before Nixon's flight from Washington, D.C., to San Clemente, California. **Washington Post**, Feb. 9, 1973, p. 27.

Feb. 10-March 10 The U.S. Navy conducts water impact and towing tests of the space shuttle's solid propellant boosters at the Long Beach Naval Shipyard in California. The test hardware includes a 77%-scale model of the booster that is dropped from heights ranging from 0.3 meters to 12 meters at different angles. The model is also towed at speeds ranging from 3.7 kph to 14.8 kph. **NASA Release** 22-73.

4 **Feb. 15** NASA announces that the Pioneer 10 probe, on its way to Jupiter, has crossed the Asteroid Belt. Launched in March 1972, the spacecraft traverses 430 million kilometers through the belt with no damaging hits from asteroid particles. Pioneer 10 makes its closest approach to Jupiter in December and continues toward Saturn, exiting the solar system in 1983. **NASA Release** 73-27.

Feb. 15 The Soviet Union launches its Prognoz 3 research satellite into orbit with a 200,000-kilometer apogee and a 590-km perigee. The objective of the 845-kilogram spacecraft is to explore corpuscular, gamma and X-ray solar radiation, among other phenomena, to determine the effects of solar activity on the interplanetary medium and magnetosphere of the earth. NASA, **Aeronautics and Astronautics, 1973**, p.47.

Feb. 17 U.S. President Richard Nixon signs a Senate resolution redesignating NASA's Manned Spacecraft Center the Lyndon B. Johnson Space Center in honor of the late president, who died in January. Among other achievements, Johnson helped write, introduce and pass the legislation that created NASA. NASA, **Aeronautics and Astronautics, 1973**, pp. 49-50.

Feb. 22 The National Space Club holds its Awards Luncheon in Washington, D.C. Among other honors, the Dr. Robert H. Goddard

Historical Essay Award is presented to Barton C. Hacker of Iowa State University for his essay, "From Space Station to Orbital Operations in Space Travel Thought, 1895-1951." **The National Space Club News Letter**, Feb. 22, 1973.

5 **Also in February** The SS Hope, a hospital ship operated by the People-to-People Health Foundation, sails from Baltimore and arrives in Maceio, Brazil, after being equipped for communication via satellites. Under an agreement between the Communications Satellite Corp. and the foundation, the ship is fitted with a small parabolic antenna and a transmit-receiver communication satellite terminal to assess the use of reliable long-distance communications with medical teams in remote areas. NASA, **Aeronautics and Astronautics, 1973**, p. 59.

1998

Feb. 4 The first Boeing 777-300 fitted with 436 kilonewton-thrust Pratt and Whitney PW4098 engines makes its inaugural flight. **Flight International**, Feb. 11-17, 1998, p. 15.

Feb. 26 A Pegasus-XL booster air launches Teledesic's experimental technology communications satellite T1. It is described as "the first commercial Ka-band low Earth orbit satellite" and also as a "demonstrator" for a potential $9 billion system of 288 satellites for providing high-rate internet multimedia services. The satellite was previously named the Broadband Advanced Technologies Satellite. **Flight International**, March 1-17, 1998, p. 18.

6 **Feb. 27** The 3,500-kilogram Intelsat 806 is launched by a Lockheed Martin Atlas 2AS rocket. Intelsat 806 is the first of the Intelsat communication satellites able to simultaneously provide uplink and downlink TV transmissions. This particular satellite is to provide services to Latin America and Europe for about 15 years. **Aviation Week**, March 9, 1998, pp. 25-26.

7 **Feb. 28** Teledyne Ryan Aeronautical Co. begins flight tests with its Global Hawk reconnaissance drone. The 35-meter-span remotely piloted aircraft can remain aloft for 24 hours with a 3,000-nautical-mile radius and carries 861 kilograms of sensors. This is the greatest endurance and payload capability of a new generation of drones. **Aviation Week**, March 9, 1998, pp. 22-23.


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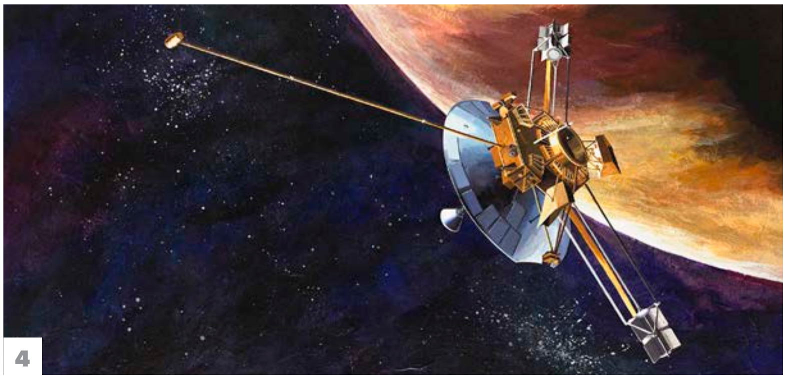
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We have landfills in space, but we don't have to

BY MORIBA JAH | moriba@utexas.edu

If you feel like rocket stages and dead satellites are crashing back to Earth with increasing frequency, you are right. Most recently, NASA's Earth Radiation Budget Satellite, an environmental spacecraft retired in 2005 and left in orbit, reentered the atmosphere in January. There was a 1-in-9,400 chance of a surviving piece harming someone, NASA said, according to Space News. In November, a 22-metric-ton Chinese rocket plunged back to Earth, also with large parts surviving reentry, but they happened to impact somewhere in the South Pacific Ocean.

Today, even if no one launched another satellite, many anthropogenic space objects are adrift in low-Earth orbit and will eventually reenter, and the problem is compounding. The root cause remains our stubborn tendency to continue to treat LEO like an open landfill of abandoned space hardware.

Until last September, the best attempt to keep the problem from getting even worse was a 20-year-old United Nations guideline, so called because it is nonbinding. This guideline urges space operators to ensure that their used rockets and defunct satellites will fall from orbit within 25 years of the end of their missions. A slight improvement came in September, when the U.S. Federal Communications Commission published a rule requiring U.S. licensed satellite operators, or those abroad seeking to enter the U.S. market, to ensure that their objects will burn up within five years after the end of their operations.

This rule and the international guideline it is intended to replace in the U.S. are deficient, mainly because the "disposal" they speak of can be an uncontrolled one. Disposal is defined as simply ending the potential for the object to interfere with space operations and activities. We can see the deficiency demonstrated clearly in the case of NASA's environmental satellite: It reentered 17 years after its retirement, well within the guideline, and yet its debris still posed a risk to us on the ground, however small. The fact that it entered over the Bering Sea and injured no

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