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AIAA
SHAPING THE FUTURE OF AEROSPACE

An X-51A Waverider under the wing of a B-52 Stratofortress in an artist's concept.
U.S. Air Force

On the cover: Text to come. Description of cover here.

Image credit: Credit text

AEROSPACE AMERICA

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IN THIS ISSUE

Cat Hofacker

As our staff reporter, Cat covers news for our website and regularly contributes to the magazine.

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Moriba Jah

Before becoming an associate professor at the University of Texas at Austin, Moriba helped navigate the Mars Odyssey spacecraft and the Mars Reconnaissance Orbiter from NASA's Jet Propulsion Lab and worked on space situational awareness issues with the U.S. Air Force Research Laboratory.

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Jan Tegler

Jan covers a variety of subjects, including defense. He's a frequent contributor to Defense Media Network/Faircount Media Group and is the author of the book "B-47 Stratojet: Boeing's Brilliant Bomber," as well as a general aviation pilot.

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Sarah Wells

Sarah is a science and technology journalist based in Boston interested in how innovation and research intersect with our daily lives. She has written for a number of national publications and covers innovation news at Inverse.

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DEPARTMENTS

For the Biden team, a "wicked" aerospace problem

Assuming covid-19 is tamed and a giant asteroid or comet isn't spotted heading our way in 2021, climate change will resume its place as the most pressing science and technology issue facing humanity. On this topic, the incoming administration of President-elect Joe Biden might soon experience the power of inertia, as in the "resistance of any object to any change in its velocity," as Wikipedia defines it.

The Democratic Party platform has inertia in the forward direction on climate change, calling for achieving "net-zero" carbon emissions no later than 2050 for the economy overall, in part by creating a "clean, 21st-century transportation system," which presumably would include cleaner air transportation. This forward inertia is not matched by the U.S. government, which became practically motionless on the issue under the Trump administration.

Restoring that motion won't be easy. In the aerospace sector, doing so could mean stretching out the timetables for accomplishing other goals that many reasonable people applaud, including clearing the way for supersonic air travel, catching up with rivals on hypersonics research, and reviving human exploration of the moon.

Taking on climate change here in the United States is what the theorists call a "wicked problem," meaning one that defies logic and predictable outcomes. If the Biden administration attempts to jar the bureaucracy into motion through small, painless bumps, the climate won't wait and innovators around the world will continue leaping ahead of the United States. What about retooling the entire federal government to meet the climate challenge? A year ago at the AIAA SciTech Forum, former NASA official Lori Garver pointed to something like that path, calling climate change the "No. 1 global challenge of our time," and suggesting that the talents of NASA and the nation should be reoriented to it much as they were marshaled to beat Russia to the moon in the 1960s. That makes total sense, but it also sounds like a political nightmare, which is why climate change is such a wicked problem here in the United States. Progress would likely bog down in time-sucking side debates over where to spend the money and how to best reshape the bureaucracy.

So, I don't know exactly what the solution will be. I suspect, though, that the private sector will be a big part of it. We might discover that relatively small nudges to the government apparatus through new research initiatives, tax changes or enhanced international collaboration will have an outsized effect by unleashing private sector innovators in areas such as fuels, propulsion, carbon capture and more. With luck, we'll see a whole new class of Elon Musks emerge in the area of clean energy. ★

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

Together, We Persevere

January is traditionally the month when everyone starts anew, refreshed by the optimism of a new year. And right now, we need it. I think we all agree 2020 was one of the most trying years in our memories. It has been for the aerospace industry too. And while we're still in the midst of the pandemic, the new year has ushered in a realization that brings hope – our industry's commitment to perseverance.

In last month's *Aerospace America*, Editor-in-Chief Ben Iannotta inspired us when he recounted multiple examples of perseverance in our industry during 2020. We're once again launching astronauts from U.S. soil to the International Space Station thanks to public–private partnership. Three countries have spacecraft headed to Mars. As Ben aptly said, "There are literally too many examples of progress this year for me to allude to all of them here."

One illustration of the industry's perseverance was seen at the December SciTechxWebinar, "Flying is Safe – Is Air Travel?". Executives from the global air travel ecosystem – Delta Air Lines, The Boeing Company, Airbus Americas, Hartsfield Jackson Atlanta International Airport, and Aerospace Industries Association (AIA) – joined AIAA to discuss how they are working together to build the traveling public's confidence back with real data and communication. We then took a deeper technical dive into what and how data are being tested, the results, and the next steps to ensure that air travel is safe. We heard a clear message that should give passengers and employees the comfort they need to confidently return to flying – a resounding "yes," air travel is safe. The panels described how the multi-layered approach of airplane and cabin disinfection with new technologies to further enhance health safeguards, are working in combination with consumer safe behaviors such as mask-wearing and handwashing. We were proud to help support the industry's messaging around this critical initiative.

Perseverance also reigned through AIAA this year. COVID-19 didn't hold us back from publishing technical journals and papers, recognizing and honoring member accomplishments, and gathering as an industry community (albeit virtually). In fact, we brought together close to 20,000 industry professionals between April and December at numerous virtual events. Moving in-person events to online platforms allowed us to reach more participants who could safely attend from their homes. Lessons learned from virtual events and the unforeseen benefits have sparked a new commitment once we are out of the pandemic. Our future events will be hybrid in nature – part in-person, part online – to maximize our reach and impact.

In 2020 the industry rose to the occasion multiple times. But we shouldn't be surprised. After all, perseverance is in our industry DNA.

In the 1967 Apollo 1 fire, industry pulled together with NASA and completely redesigned the Apollo Command Module, which ultimately was used in six lunar landings. Following the 1986 Space Shuttle *Challenger* tragedy, NASA led a comprehensive review of safety risks across the program and substantially improved the overall safety of the Space Transportation System. In 2003, the loss of the Space Shuttle *Columbia* shined a light on the safety culture at NASA and informed the design of human-rated space flight vehicles to follow.

Who remembers the International Space Station almost didn't get through Congress in 1993? It was the late Rep. John Lewis (D-GA) who cast the deciding vote to continue the program despite years of cost overruns and schedule delays. Just a few months ago, the ISS celebrated its 20th anniversary in orbit. Humans have been living and working in space for two solid decades.

September 11, 2001, was a day of immense loss none of us will forget. The resulting 9/11 Commission exposed the weaknesses of air transportation security, but also empowered the United States to take definitive, positive action. Through Vision 100 – the Century of Aviation Reauthorization Act in 2003 and the National Intelligence Reform Act of 2004, the United States has been able to address many of the commission's recommendations. Steps such as enhanced passenger prescreening, stronger means of identifying dangerous cargo, and much more have allowed us to avert another terrorist attack for nearly 20 years.

Perseverance is about meeting the challenge and building a better future. It also means being willing to try new approaches, taking smart risks, and being resolute in assuring a better future. For over a century, the aerospace industry has persevered because by its nature it challenges the conventional wisdom to create new ways to extend humanity's reach to the sky. The benefits of this work are clear in the economic impact and inspiration to all. We must be willing to continue challenging the norms – willing to try new methods and take on risk.

While COVID-19 is still with us, these moments in history can keep inspiring us – when we rallied as an industry, learned from the crises we faced, and moved ahead with renewed resolve. We will continue to adapt. Plus, on the immediate horizon of 2021, we have so much to look forward to; spacecraft arrivals at Mars, the growth of the private space enterprise with suborbital flights and missions to the ISS, and the launch of the James Webb telescope are reasons to celebrate and strengthen our hope.

Let's set our sights on these upcoming moments and do what we can to keep them on track. Remember, together, we persevere. ★

Dan Dumbacher
Executive Director, AIAA

How many moon walkers?
In the November issue, we misstated the number of people who have been to the surface of the moon ("5 necessities for thriving in space"). The correct number is 12.

Let's try this again
In the December Year-in-Review issue, we cut off the last few words of the article by the Space Transportation Technical Committee. So we've printed the article correctly at right.

LET US HEAR FROM YOU Send letters to letters@aerospaceamerica.org.
Letters may be edited for length and clarity and may be published in any medium.

Crewed launch returns to Kennedy Space Center

BY DALE ARNEY

The **Space Transportation Technical Committee** works to foster continuous improvements to civil, commercial and military launch vehicles.

U.S. astronauts were launched from NASA's Kennedy Space Center in Florida for the first time since 2011. For the Demo-2 mission, Bob Behnken and Doug Hurley flew to the International Space Station aboard a **SpaceX Crew Dragon** capsule atop a Falcon 9 rocket in May, clearing the way for November's Crew-1 launch. Boeing prepared for an uncrewed test flight of its Starliner capsule after the initial December 2019 uncrewed flight on a United Launch Alliance Atlas V rocket was shortened due to a software error. In February, a Northrop Grumman Antares rocket delivered a Cygnus cargo vehicle to the ISS. SpaceX launched its 19th successful Cargo Dragon resupply mission to the ISS in March.

In August, NASA completed the fourth of eight **Green Run tests for its Space Launch System** at NASA's Stennis Space Center in Mississippi. The test verified the main propulsion system components were operable and leak-free. Northrop Grumman fired a full-scale version of SLS's solid boosters in September, and in July, Aerojet Rocketdyne completed all of the propulsion hardware for the first crewed flight of the SLS.

▼ **The core stage for a** Space Launch System rocket was transported from NASA's Michoud Assembly Facility in Louisiana to its Stennis Space Center in Mississippi.
NASA

SpaceX launched its **100th mission** in August, and in April its Falcon 9 rocket became the most flown active rocket with its 84th launch. An August launch of a Falcon 9 flew a booster core for a record sixth time; a Falcon 9 payload fairing was reused for the first time in November 2019. SpaceX performed 150-meter test flights in August and September of its Starship prototype at its south Texas facility.

ULA in July launched NASA's Perseverance rover to Mars on an Atlas V rocket. Blue Origin delivered a pathfinder **BE-4 engine**, and Northrop Grumman completed the first qualification test for a strap-on booster. Both are being developed for ULA's next-generation rocket, Vulcan Centaur.

Virgin Galactic's VSS Unity spaceplane conducted two unpowered glide flights, one in May and one in June. After a failed attempt in July, California-based Rocket Lab's Electron satellite launch vehicle returned to flight in August. That flight also included the first flight of Rocket Lab's new Photon spacecraft bus. Also this year, Rocket Lab received a launch operator license from FAA allowing launches from NASA's Wallops Flight Facility in Virginia starting in late 2020.

In May, the **Long March-5B**, China's heavy-lift rocket intended to support a space station in low-Earth orbit, delivered an uncrewed version of its next-generation spacecraft. In March, China's first launch of the **Long March-7A**, upgraded to include nontoxic propellants and modular systems, failed to reach geosynchronous transfer orbit.

In September, **Europe's Vega rocket returned to flight** to deliver 53 satellites for 21 customers. In July, the United Arab Emirates launched a probe to Mars aboard Japan's H-2A rocket, and China launched its Tianwen-1 mission to Mars aboard the Long March-5. Russia launched the 27th, 28th and 29th Gonets-M satellites in September on a Soyuz rocket. It had launched the 24th, 25th and 26th satellites in December 2019 on a Russian Rokot rocket. It was final launch of a Rokot; the first one debuted in 1990.

In July, Israel launched its **Shavit-2 smallsat rocket** for the first time since 2016. Japan launched the final H-2 Transfer Vehicle to the ISS in March. In April, Mitsubishi Heavy Industries in Japan test fired its LE-9 engines for 240 seconds in preparation for its next-generation H3 rocket. ★

AERO PUZZLER

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

Designing for Titan return velocity

Q. A junior engineer has been tasked with designing a small reentry body that will return hydrocarbons from Saturn's moon Titan. He runs the design by his hypersonic aerodynamics professor, predicting that the small nose radius will keep drag low during the reentry at return velocity and permit precise targeting of the landing zone. "Well," says the professor, "even if you start with a sharp reentry body, at best you'll end with a blunt one." What does the professor want the former student to realize?

Draft a response of no more than 250 words and email it by noon Eastern Jan. 18 to aeropuzzler@aiaa.org for a chance to have it published in the February/March issue.

FROM THE DECEMBER ISSUE

A TEACHING MOMENT: We asked you why a student who wrote a chapter titled "Reduction of turbulent flow for optimized maneuverability" should not try flying his prototype aerobic aircraft. There was no winning response so we asked professor Clint Balog of Embry-Riddle Aeronautical University to provide an explanation:

In theory, laminar flow would be preferred if it could be maintained along the entirety of the airfoil. However laminar flow, although it induces less frictional drag, tends to separate along the airfoil under real-world conditions. This separation occurs when the boundary layer does not have enough momentum to resist the adverse pressure gradient along the airfoil. Flow separation results in loss of lift, as well as increasing the "pressure" drag. Turbulence generators, called vortex generators, are even sometimes used to "trip" the boundary layer to make it turbulent. Turbulent boundary layers have much larger momentum, and thus they are able to resist the adverse pressure gradient, enabling the flow over the wing to reach the trailing edge of the wing without separation. As a result, lift force is preserved, and pressure drag is avoided (which may have a much greater effect than frictional drag). So that turbulent flow isn't just for executing maneuvers, or for tightening up a turn, although in some circumstances it can accomplish those things, it is for every aspect of lift generation. So in reality an optimized turbulent boundary layer flow is preferred.

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

Air launch with a twist

BY CAT HOFACKER | catherineh@aiaa.org

▲ **Aevum's autonomous** unpiloted aircraft, part of its Ravn X launch system, would loft a two-stage rocket carrying satellites to orbit.

Aevum

Every space launch company has its own secret sauce it believes will set it apart from competitors. For Aevum Inc., that something is an autonomous, unpiloted, rocket-launching aircraft.

The 4-year-old Alabama startup in December unveiled this jet-powered reusable carrier drone that would be paired with the launch vehicles the company is also developing to form Ravn X, a launch system for satellite payloads of up to 500 kilograms, depending on the orbital altitude.

With its sleek black-and-white fuselage and tapered nose, the 24-meter drone more closely resembles the design of a supersonic airliner than the non-supersonic carrier aircraft that rivals including Northrop Grumman and Virgin Orbit fly to air-launch their rockets.

That resemblance is intentional, Aevum founder and CEO Jay Skylus says. The Ravn X aircraft would be a precursor to a future variant, Ravn without the X, that would fly at supersonic speeds. This, Skylus says, would give Aevum an edge over its air-launch rivals as well as companies that launch conventional rockets from the ground. "Our model is fundamentally different and really, I believe, built to be sustainable as opposed to our peers and industry that are dependent on this launch-site infrastructure."

Ravn X, which has yet to fly, could take off from any of the 11 FAA-licensed spaceports in the U.S. In the first operational flight scheduled for mid-2021, the carrier drone will speed down a runway at the Cecil Spaceport in Jacksonville, Florida, its two-stage rocket strapped to its belly. Inside will be an undisclosed number of three-unit and larger cubesats for the U.S. Space Force. The $4.9 million experimental mission dubbed ASLON-45, short for Agile Small Launch Operational Normalizer, is part of a Pentagon plan to build up the small-launch industry for more rapid small satellite launches.

Once aloft, software will command the rocket to be released at an altitude between 9 and 18 kilometers, and the drone's flight computer will direct the drone either back to Jacksonville or to another destination calculated by an algorithm, based on data including air speed and weather conditions from the onboard sensor suite.

Aevum expects this flexibility of launch and landing sites to be especially attractive to military customers. "This makes it almost impossible to predict where Ravn X is going to take off from" and land, Skylus says. "So our adversaries who are targeting launch sites to keep us on the ground, this will be nearly impossible for them for intercept because we can literally change each launch site within the hour."

Leading up to the Jacksonville launch, Aevum plans to conduct a series of taxi and flight tests to verify the Ravn X hardware and software, the goal being to earn an airworthiness certificate from FAA. That certificate is not a requirement of the ASLON-45 launch, but would set Aveum up for future launches, Skylus says, because Ravn X could then potentially fly from any U.S. airfield with a 1.6-kilometer (1-mile) runway the drone needs for takeoff. ★

MATT ONDLER

POSITIONS: Chief technology officer at Axiom Space since January 2020; president and CEO of robotic engineering firm Houston Mechatronics, 2014-2019; at NASA's Johnson Space Center, chief of the Software, Robotics, and Simulation Division, 2007-2011.

NOTABLE: Oversees hardware and technology development at Axiom Space, which last year received a $140 million contract from NASA to build the first privately owned module for ISS; co-founder of Houston Mechatronics, which builds undersea robots for installation and repair of underwater oil and gas pipes; worked at NASA Johnson for 28 years, including a two-year stint as project manager for Project Morpheus, an initiative to quickly build and fly a low-cost lander that concluded in 2014 after handful of test flights, including a 2012 flight in which a prototype crashed and caught fire.

AGE: 57

RESIDENCE: Houston

EDUCATION: Bachelor of Science in aerospace engineering, University of Colorado at Boulder, 1986; Master of Business Administration, University of Houston, 1993.

Tomorrow's station operator

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"If you build it, they will come" — that's what Matt Ondler and his colleagues at Axiom Space are betting in their plan to erect the first privately owned space station. Assembly will start in 2024 when the International Space Station's robotic arm attaches the first of four planned Axiom modules to the Node 2 port to begin a couple years of confidence building before the modules separate to form a free-flying station. As chief technology officer of the roughly 100-person Houston company, Ondler oversees the construction of these and future modules that Axiom plans to build for in-space manufacturing, welcoming space tourists and other needs. I spoke with him via video call ahead of AIAA's virtual ASCEND conference in November. Here is our conversation, compressed and lightly edited. — *Cat Hofacker*

Q: The International Space Station celebrated 20 years of continuous human presence in November, but both NASA and U.S. lawmakers agree the U.S. modules are nearing their end of life. Why is a commercially owned station the next step?
A: There's a lot of advantages for NASA, of course, but also for commercial space. The advantage for NASA is that of the $3.5 billion a year or so that NASA spends on the International Space Station, only a fraction of that, about $500 million or so, is used for science and technology development. So there's a big overhead in maintaining the station, and by having a commercial alternative where NASA can still go procure those kind of services in terms of research and technology development, it frees up a bunch of money for NASA to do something else, to go do the next big thing — to go the moon or on to Mars. NASA has shown and proven over the last 20 years how to keep humans healthy in space and how to do real work in space, and so it's a good time to try to exploit those and move the industry beyond to start manufacturing in microgravity and create a new commercial enterprise.

Q: Paint me a picture of Axiom Station. Besides being privately owned, how will this station be fundamentally different from ISS?
A: The first and most important is that our space station is completely funded through investment, through revenue that we generate from our business, and so it will be owned by Axiom Space and wholly operated by Axiom Space.

> Ondler later got back to me and clarified that Axiom's $140 million firm-fixed price contract is for the company to provide NASA with data and lessons learned from designing and building the initial modules. Axiom plans to cover the cost of designing and building the modules through a combination of investor funding and revenue from other parts of the company including private spaceflight missions to ISS. — *CH*

Fundamental business needs will drive how we operate the station, how we build the station, how we maintain it. We have to be able to build and maintain and operate a station at a cost that is much lower than the ISS, but we can do that by leveraging the technology and the capability that ISS has proven over the years. The first two Axiom modules will have the ability to house crew, to house payloads, lots of equipment, storage and things like that. Then the third module is dedicated to research and manufacturing. We want to accommodate heritage NASA experiments as well, so take a payload from the ISS and bring it across the hatch and install it into the research manufacturing module. The fourth module is a power thermal module, so it has large solar arrays, it has a three-person airlock that'll be more capable than the one on the ISS. From there, which modules we build depends on the market. If there's a market for flying crew, then we'll build another habitation module. If there's a huge market for research, manufacturing, we'll build a research and manufacturing module next.

Q: What do you envision that the customer breakdown for the future Axiom Station will be?
A: It's really a multipronged business approach and customer base, one of which is private astronauts. Those will come in a couple different flavors: Some are wealthy individuals that people like to call tourist astronauts. We think there's also a big market for professional astronauts that are from countries that may already participate in the ISS, but they don't get the opportunity to fly their astronauts as often as they would like. There's another group from that category that don't necessarily participate in the ISS or don't have a way to really participate in the space program, but want to for their own countries' interest, for their own countries' prestige, to stimulate the STEM fields in their countries. And then we hope at some point to be able to fly individuals that might be working at companies that are interested in doing manufacturing in space, for example. Another big piece of the business model that I think will end up being the largest and most profoundly world changing is on-orbit manufacturing, the ability to leverage microgravity and to build things you just can't build on Earth. It has the promise of being a game-changer, to overuse the phase, but to really create entire new industries where we hope to be building space station modules specific for customers so that they can scale up their manufacturing. Another market segment that's interesting is people who want to create media in space, whether it's movies or commercials, and that's something NASA can't really do. NASA can't really be seen as promoting a particular company, and by

"Another market segment that's interesting is people who want to create media in space, whether it's movies or commercials, and that's something NASA can't really do."

“Our goal is to launch the first module in September 2024. The second element is launched about nine months later and then the third element about six to eight months after that.”

simply having a commercial space station, we can foster some of those markets as well. The last big piece, too, is to be able to be a place where NASA can continue to do fundamental research and do experimentation, technology development for, say, going to the moon or Mars and also a place to train their own astronauts for future missions. All those things together create what we think is a pretty robust business model.

Q: Take us inside the design process for Axiom Station and how these emerging markets are influencing those plans. For example, does the prospect of having humans onboard who are not professional astronauts require Axiom Station to have more creature comforts?

A: Each of our initial modules is being designed and developed to be either launched on a SpaceX Falcon Heavy or a Blue Origin New Glenn, and that ultimately does constrain the size of the module. We have a partnership with Thales Alenia to build the first two modules. They’ve built about 40% of the modules on ISS, so they have a lot of expertise. More importantly, they have all the tooling and friction stir welding machines and all the industrial capability to build the module. That really allows us to get a good start on our station, but subsequent modules may be very different. There may be large inflatables, we may do some construction in space, and that allows us to build things that aren’t necessarily constrained by the launch vehicle itself. So the future will end up being a little different, but to get that foothold you have to launch those first modules on a launch vehicle, right? On the overall design, some attention was paid to the aesthetic and the comfort and the ease at which

people can integrate, to be able to have them bring their own phones and iPads and plug into the network, easily be able to share their experience with their family and friends and with Instagram, for instance. The other part is taking advantage of advances in computing and processing power. We want to have a much more automated station where we don't need a lot of crew intervention; the intervention that might be required is done more from the ground. And then we hope to have some pretty interesting robots in the future on the station. Maybe a robot internally that helps prepare for the next crew or moves cargo around. This trend toward more automation means less requirement to have professional, trained astronauts to operate the station, but we will always have professional Axiom astronauts onboard as well to handle off-nominal situations.

▲ **In this rendering of** Axiom Station, the station has been assembled into a collection of crew and cargo modules that supports private spaceflight visits and activities including on-board research and manufacturing.
Axiom Space

Q: And how is Axiom making sure it can accommodate companies or government agencies who might want to build and attach their own module to Axiom Station?

A: We want to be positioned where we're a logical choice to build that module for them as well, but if there was someone else who built a module and it met our interface requirements, they would certainly be allowed to come and attach to our station. We're designing all the modules to have what are called the common berthing mechanisms that are the same as on ISS, and so having that common berthing element or having a standard NASA docking system means the ability for all vehicles to dock with us, as well as being berthed. Those are the primary interface requirements, and then it just depends on what they want to do with that module: It's dedicated to manufacturing, it's dedicated to a movie studio.

Whatever it happens to be, we would have to work through that. We're really trying to build with our station an infrastructure and a capability that's very, very flexible to allow lots of different customers. For example, we want our payload accommodations to be as close to a terrestrial laboratory as possible. So if there's a researcher at a Johnson & Johnson or a DuPont who has some equipment they're running in their lab on Earth, we want to be able to take that experiment and almost identically fly it on our station and plug it in. We want to have those kinds of services that are very common on Earth and have them on our station as well: the ability to plug in the same kind of power that you plug in in the lab or they get on the Wi-Fi just as easily as in the lab. That's the goal for our payload customers. We think the path is that we fly experiments and prototypes for customers to prove out a particular technology, and then we find ways to scale that manufacturing. That could be in our existing modules; it could be that the scale of the manufacturing that's required would require an additional module that's dedicated to that. We have the flexibility to accommodate all those things.

Q: There's a long way to go from where we're talking in 2020 to that vision becoming a reality. What absolutely has to happen for all this to come together?

A: There's a few long poles. One is we certainly need continued support from NASA. It is very helpful and important for us to have the opportunity to start our station attached to the ISS. The ISS provides some services to us that we don't have right away, such as power and communications with the ground. And then the ISS becomes, we hope, an early customer for research, exploration technology maturity and hosting NASA astronauts, similar to how NASA became a customer for the SpaceX Dragon capsules. The government being able to be a future customer and provide some funding to help private companies is important, and so that continued commitment certainly plays a big part in it. But we also have an interesting challenge in that we have a short window of opportunity. There will be a day in which ISS is no longer viable and too expensive to maintain and it will be at some end of life, and it doesn't do us any good to show up the day before that. We have to get there relatively early. Our goal is to launch the first module in September 2024. The second element is launched about nine months later and then the third element about six to eight months after that. And then there's a bit of a gap to launch our fourth element because it's quite different than the others and so will require some design work in addition to what we've already done for the first three modules. That's a relatively short time in the aerospace business when you're building such a complex thing, so I think that's going to be one of the challenges: to continue to move fast. Everything else is generally an engineering problem. We pretty much understand how to build a space station, how to keep humans healthy and alive on the station, how to accommodate payloads. We just have to go solve some engineering work to do it right.

Q: In your mind, what are some of those biggest engineering challenges?

A: One is the Common Berthing Mechanism, or CBM, through which vehicles visit ISS and that will also be our approach to connect modules and dock vehicles with Axiom Station. The CBM is made up of a passive and active side that are on each module that are being put together. The passive side is just hardware, while the active side has mechanisms and electronics and powered bolts that pull the modules together and then bolt them together. When vehicles such as the Japanese HTV visit the ISS, they are captured by the ISS robot arm and then berthed. The ISS will have the active side and the HTV will have the passive side. Since the completion of ISS, every vehicle that comes to visit that is not docking carries the passive side, therefore people only build the passive CBM these days. It's been at least 10 years since anyone has built an active CBM, and even then the electronics were likely obsolete. We need to solve that problem very quickly because we're going to have a lot of active berthing mechanisms to accommodate our ability to add modules. So that's one problem solved. Another is when we are a free flyer, we will be using control moment gyros on the order of the size of the ones on ISS. It's been a long time since someone built those, and they are a bit of an engineering marvel so there's a long lead to develop those. We're also flying a pretty unique propulsion system: oxygen methane. One of the reasons we're doing that is it's a green propellant, so it's relatively easy to test on the ground because there's no toxic chemicals. The other big reason is that we can take the carbon dioxide that's exhaled by the crew and turn that into methane. Our studies show that with the crew of six onboard, we can create all the propellant that we need just from the crew producing $C0_2$. That makes a very compelling business case because you reduce your resupply propellant greatly, but no one's flown a methane oxygen system yet, so there's some development work there. We plan to test some of that hardware while the initial modules are still docked to ISS.

Q: What lessons have you taken from the early years of ISS?

A: The list is probably very, very long. One interesting one that we're working pretty hard right now is the whole idea of stowage, which not a lot of attention was paid to in the early days of ISS. It ends up being a big problem: not only stowing the stuff that you want to use, but the stuff that you've already used or

need to throw away and how do you manage all that? When you talk to crew members, they still tell horror stories about how they spent an entire afternoon trying to find a seven-sixteenths Allen wrench. The other is trying to build for replaceability. So, for example, there is our networking and computer infrastructure we're designing so that swapping out should be as easy as replacing your laptop every five years. We're also looking at innovative sources for those kinds of processors — automotive parts, for example. If you look at a modern automobile today, it's pretty much a computer marvel where there's millions of lines of code and all kinds of sensors being addressed and fused together. Those are parts that are available that we want to try and see if we can use for an aerospace application because they're much cheaper, there's more suppliers available, and we have the ability to upgrade in the future.

Q: How do all these planned innovations contribute to the lifespan of Axiom Station?

A: We think there's a longer life simply because we are building in the ability to upgrade. There are certain things that just wear out, and the unique or different aspect of our station compared to ISS is that every one of our modules is an individual spacecraft. It gets launched by a SpaceX or a Blue Origin rocket, and then it has to approach and rendezvous with ISS, or after ISS it has to approach and rendezvous with our station. Each module is a spacecraft, therefore you could actually deorbit each module individually once it reaches end of life or if it gets damaged from a micrometeoroid strike. That allows us to have essentially unlimited life. When modules wear out, you throw those away and you bring up a new one. Another contributor to this longer lifespan is reduced operating costs. Our philosophy — because we believe we're going to be building space stations or versions of space stations for a long, long time — is we're building all the core infrastructure for the long haul. We'll have engineers that worked on the design that can support operations, and that makes the operations much less expensive. And then you throw in more automation and more capability just because the computing power is advanced, we think the operations cost should be relatively small.

Q: Speaking of lifetime, while ISS has had continuous government funding to slowly build up different kinds of activities onboard over the years, a private station like Axiom's won't have that luxury. So how do you ensure Axiom Station is profitable right away?

A: We have to always be thinking about customers and who will be our first users. We're developing those

▲ **The Axiom Station** habitation module created by French product designer Philippe Starck in 2018 is shown in an early rendering. Axiom envisions a rotating roster of professional astronauts and space tourists living aboard the future station, and enlisted Starck's help in "paying attention to the aesthetics," Ondler says.
Axiom Space

▲ **A SpaceX Crew** Dragon capsule onboard a Falcon 9 rocket is moved out of the horizontal integration building at Launch Complex 39A at NASA's Kennedy Space Center in Florida before the Crew-1 mission in November. Along with ferrying NASA astronauts, Crew Dragon capsules are scheduled to carry the first of Axiom's private passengers to the International Space Station.
NASA/Joel Kowsky

now and, where we can, we'll try to fly something early on the ISS. We have to be ready to go on day one, and the same is true with the private astronaut sales and other markets. Private astronaut sales are coming along; Axiom will begin flying private astronauts to ISS next year or early 2022.

Along with building modules, Axiom plans to sell flights to ISS and eventually Axiom Station. The first of these missions, dubbed Ax-1, is scheduled to launch three private citizens and an Axiom astronaut aboard a SpaceX Crew Dragon capsule for an eight-day stay on ISS, where the tourists would sleep in a location aboard station to be determined. — *CH*

In-space manufacturing is another market on the cusp. It's almost like the early days of the internet: You have that capability, but people weren't exactly sure what we'd do on the internet. The same with the smartphone; we weren't exactly sure what kind of apps would be usable, and now you see thousands if not millions of potential applications. I think the same thing will happen with in-space manufacturing. One company will discover a little thing that has a good business case to manufacture, which will lead to other companies and other ideas, and soon it's an explosion of ideas and capability. But those first ones are going to be pretty time-sensitive and we need to try to foster that as much as we can. The big thing is we have to build our station in a very timely manner. We rely on the ISS in the early modules for power and berth, thermal protection and even a comms link, and it's not until our fourth module gets up there that we have true independence capability from the ISS. So we have to make sure we get that done before ISS' end of life.

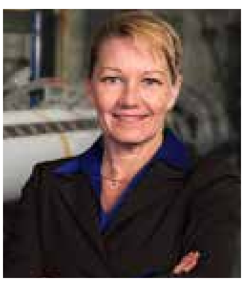
Q: Say it all goes according to plan: It's 2050 and Axiom Station is operating. What is the long-term future that Axiom envisions in low-Earth orbit — multiple space stations? Crew capsules coming and going?

A: We have a 40-, 50-year vision that in 2050 there's multiple space stations in low-Earth orbit. There's a space station that might be rotating to create some artificial gravity to make it easier to live and work long term, with some maybe counter-rotating parts or some separated parts to still maintain the microgravity environment for manufacturing. Those large space stations might have hundreds if not thousands of people. We think access to space will be much less expensive, and so lots of opportunities for all kinds of people to live and work in space. We also think that in 2050 we will have discovered a number of things that can be manufactured in microgravity to the point that it really has created an entire new industry. And the benefits of those things, whatever they are, will improve everyone's lives — whether it's superhigh-performing fiber optic cable that can only be made in space or perfect retinal implants or other biological things that we figure out how to make in microgravity. Our hope for the future is that there's this incredible manufacturing and capability in low-Earth orbit. And not only in low-Earth orbit, probably in orbit around the moon and other places that we're building stuff and lots and lots of people are living and working in space. ★


AIAA
CONGRESSIONAL
VISITS DAY
WEEK OF
15 MARCH 2021
New approach, wider reach, same great grassroots advocacy event
Given the continued health and travel concerns related to the coronavirus pandemic, the Institute's 23rd annual CVD program will be unlike any previous year—it will be entirely virtual. It will also take place over an entire week. We hope that this allows for more AIAA members to participate and ultimately provides an opportunity to present our community's message to more congressional offices.
Register now to help raise awareness for the aerospace community.
aiaa.org/CVD2021
AIAA
SHAPING THE FUTURE OF AEROSPACE

Meet your AIAA presidential candidates

Laura McGill



CURRENTLY: Preparing to become deputy director of nuclear deterrence at Sandia National Laboratories in January, a new position created to oversee development, production and management of the U.S. nuclear stockpile.

NOTABLE: Oversaw 7,8000 engineers as the Raytheon Corp. vice president of engineering for the former Missile Systems division, 2015-May 2020. As chief engineer, 2004-2006, oversaw development and production of the Tomahawk cruise missiles primarily launched by the U.S. Navy; Inducted into the National Academy of Engineering, October 2019.

AIAA RECORD: AIAA member for 40 years since joining as an undergraduate student; fellow since 2007; led and participated in a variety of AIAA executive and technical committees, including chair of the Ground Testing Committee, 1998-2000; currently chair of the Honors and Awards Committee, since 2019. Member of AIAA Board of Directors/Trustees, 2005-2018.

AGE: 60

RESIDENCE: Tucson, Arizona

EDUCATION: Bachelor of Science in aeronautical and astronautical engineering from the University of Washington, 1983. Master of Science in aerospace systems from West Coast University, 1992

FAVORITE SAYING: "Strive not to be a success, but rather to be of value." — Albert Einstein

Why she wants to be president >>

Our membership thrives on innovation. We're all in this industry because we love being at the leading edge of capability and performance for the systems that we work on, so I think that does translate to the institute and what we're able to do and leverage what we've all learned about this new environment we're in. It's kind of an inflection point for us to go take all that and use it to evolve and invigorate the membership and our capabilities as an institute to continue to advance the industry as a whole and the working professionals to support it.

No. 1 priority >>

AIAA has been such a great aspect of my professional career, but also has given me great personal satisfaction, going from the wonderful, incredibly smart and talented professionals that I've met and been able to work with over the years to the great new ideas and capabilities that it's exposed to me. I value it so much and it's been so much a part of my life, I want all our members to be able to experience that. I want our members to not just be members, I want them to be engaged, to be able to recognize that there's all these benefits available to them. And I want to structure AIAA so it makes those resources more directly accessible and available to our members so they will realize all those benefits of membership. That's why I'm going after increased engagement. Engagement will result in broader membership, but that's not the goal. The goal is for our members to really get the same appreciation for their membership that I have had.

Staying relevant >>

There's three aspects of that. The first is I want AIAA to be a great resource for our members to help them in their everyday work. It's been really rewarding for me to be able to reach out to people I've worked with over the years through AIAA, and be able to get information or bridge partnerships between organizations that have actually helped me in my everyday job. I want to be able to do that for members, make those resources more accessible and make them aware of what the opportunities are, to build on those aspects that make them more successful in their everyday work. The second element is to support their career advancement, by helping them recognize what their opportunities for career advancement are. A lot of us are engineers and scientists in AIAA, but that can evolve into numerous different career paths as technical experts, as chief engineers, program managers. All that builds on those technical foundations, and AIAA can take a better role in helping members to realize their career aspirations in any one of those different directions they might want to take. The third element is one that's been greatly satisfying for me with AIAA: I have a lot of interest in aerospace and technologies that aren't necessarily a key part of my everyday job. I love that I get exposed to those through forums, in exchanges with other members. I want our members to realize that benefit, that they could explore for their personal satisfaction

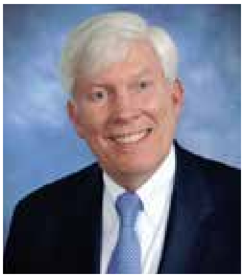
Continued on Page 20

"Shaping the future of aerospace" — that's the goal of AIAA and the task given to each president-elect, chosen every two years by members to help guide the institute initially as a member of the Board of Trustees and then as president beginning a year later. Both candidates have ideas for how to help guide the institute out of the covid-19 pandemic and make the most of operational changes inspired by it. They also have big ideas for how the institute can recruit new members and better serve current ones. I interviewed each via video call for this special section and the expanded versions of the interviews online.
— Cat Hofacker

MEMBERS VOTE: Jan. 27 through Feb. 19. See www.aiaa.org/vote/

THE STAKES: Winner begins a one-year term as president-elect on May 19, followed by two years as president starting in May 2022. Winner also becomes a member of the Board of Trustees.

George Nield



CURRENTLY: President of Commercial Space Technologies LLC, the consulting business he set up in 2018 in Northern Virginia after retiring from FAA.

NOTABLE: Oversaw the licensing of 126 commercial launches and six new spaceports before retiring from FAA in 2018 after a 15-year career, the last decade as associate administrator for Commercial Space Transportation. Head of the Flight Integration Office at NASA's Johnson Space Center that established objectives for space shuttle flights, 1987-1994. Taught astronautical engineering and directed research at the U.S. Air Force Academy from 1980-1983. Rated to pilot single and multiengine aircraft.

AIAA RECORD: Member of AIAA for 47 years, including 14 years as an AIAA Fellow. Currently a member of the Board of Trustees. Completed two terms on the AIAA Board of Directors as director-technical of the Space and Missiles Group. Served as faculty adviser for the United States Air Force Academy Student Branch. Past member of the Atmospheric Flight Mechanics Technical Committee. Served two terms as chairman of the AIAA Houston Section from 1994-1995 and 1997-1998.

AGE: 70

RESIDES: Potomac Falls, Virginia

EDUCATION: Bachelor of Science in engineering science from the U.S. Air Force Academy, 1972. Master of Science, 1973, and Ph.D., 1981, in aeronautics and astronautics, both from Stanford University. Master of Business Administration from George Washington University, 2001.

FAVORITE SAYING: "Management is doing things right; leadership is doing the right things." — Peter Drucker

Why he wants to be president >>

The opportunity exists for us to shape the future of aerospace rather than just stepping back and letting it happen, good or bad, right or wrong, at its own pace. We can be leading it. That to me is the key as I think back on my many years in the AIAA. It's enabled me to get information not only about the latest technical developments, but the status of launch vehicles and aircraft designs and so forth. It's enabled me to really become a lifelong learner many years after I left school. AIAA is an outstanding organization and it has the potential to really make a difference in the aerospace community and for society as a whole.

Top-level goals >>

First would be: advance the aerospace profession. Push the state of the art, expand the envelope, discover, explore, use new technologies to deliver benefits to society. Second would be: engage and support our members. Grow our membership and then help them to become lifelong learners. Offer career development advice, recommendations and opportunities. Provide recognition for their accomplishments and enable the development of a network of friends, colleagues and acquaintances. Third would be: educate the general public. Communicate with the media; local, state, federal and international government officials; and the public at large to assist them in understanding the importance of aerospace. And then finally, inspire the next generation. I'd like to see us use the wonder of flight and the captivating nature of space exploration to gain the attention of students and to assist teachers and educators in order to make sure that we will have a motivated and capable aerospace workforce in the future.

Making membership a must-have >>

I would love to see us double our membership in the next five years, which would be very challenging, but I think it's possible. If you look at the largest aerospace manufacturing companies in the world today — Boeing, Airbus, Raytheon Technologies, Lockheed Martin and Northrop Grumman Corp. — altogether, those five companies employ more than 691,000 people. If we could convince just 10% of the workforce at those five companies to fill out an application, AIAA would more than double overnight. One of the other aspects of this is: What really is the target market for AIAA? Somehow I think people have gotten the impression that AIAA is primarily intended for aerospace engineers. That's part of the answer, but if instead we were to think of AIAA as being the professional society for people that know about, work in or are interested in aviation and space, it could significantly change how we operate. That would be a really major shift in how we've thought about ourselves, but it could open up a lot of opportunities.

Continued on Page 21

Laura McGill *Continued from Page 18*

all those technical and scientific interests that they have.

Lessons from the pandemic >>

One thing is our timelines have to be faster. If you have information that you want to convey through a briefing at a conference, key information that's important today may wait until you submit an abstract, the abstract gets reviewed and then gets put into a conference program that's a year away. We have to figure out how we accelerate that whole process so that we can get late-breaking information out to the community much faster in those forums. Another is using all the tools of technology and community, different communication forms and not thinking of those as disparate methods of communication, but really integrating all that together. Our workforce uses all those tools, so we want to be able to make it easy for our members to interact with each other. I think part of it is technological evolution, but also it's how we engage as members. We do see a lot of members who engage at their local sections, levels and regional activities, and then there's national activities. We don't always connect those together, and I think there's an opportunity to get more interactions between those two different types of events and integrate those much better than we have in the past.

Facilitate crowdsourcing >>

There's a lot of resources available through AIAA that I don't think the membership is universally aware of and taps into. Part of it is helping them to understand what those are and then continue to advance those and expand those offerings by having the community be directly involved. The analogy I'll use is crowdsourcing, where instead of the old suggestion box where things would accumulate and somebody had to go through them all and then follow up and write responses, with the crowdsourcing type of platform you have the community directly engaged in problem solving. Somebody can put out a request, "Hey does anybody know how to do this?" and you can get immediate responses from the crowd. And not only that, the crowd vets the responses to questions. It also really engenders a lot of community engagement to solve problems that are relevant. The Engage platform is a great vehicle. I think it could be expanded for some additional capability, but it's a great start and it shows AIAA is moving in the right direction to engage the broader community.

Demonstrating diversity >>

I think AIAA has a great power of our membership to demonstrate how we can be a very diverse and inclusive organization. It allows our members to see other members engaged in different ways and hold up those role models that we have within AIAA and the successes that those people have had. People seeing people who look like them in successful roles goes a great way toward them wanting to join the community. And we do struggle in all the tech fields, STEM fields, of getting more diverse people interested and going all the way. It's what I love about AIAA; they really extended their K through 12 programs to really reach out to younger people who are thinking about their careers, to get them to see what a professional life could be, a STEM-type of career. I think AIAA has a great opportunity to continue to build on that and then build up a much more diverse aerospace workforce.

Bringing in new topics >>

Here's where I think AIAA has an advantage over a lot of other professional societies. If you look at most of them, they're focused on a discipline like mechanical or electrical or test engineering. But aerospace is about systems. That's why it's so exciting to work in this industry and be part of AIAA; because we work on systems, we all in our home organizations interact with people who are working through all those hundreds of science and engineering disciplines that all go into making our systems. The key is how do we bring that into AIAA and expand the content of our forums to include all those other aspects? It's not even just technical: There's the programmatics and understanding what's going on in regulatory environments and being compliant to regulations. All those are other aspects that we have to deal with in developing our systems, so that should be part of the content in a society that is for aerospace professionals. We should be looking at all those aspects, because those all add to the resources that we can then bring back to our home organizations. It gets back to crowdsourcing. The crowd will tell you where you need to go, and I think we can use that as part of our guidance.

Metrics for success >>

There are ways to track engagement and increase membership as a result, but the real goal is engagement. I want our members to feel like they are engaged in the society and taking advantage of all the resources available to them. Participation in conferences is one metric that we've always tracked: how many people come to our conferences, our various forums. But that's just one element. As we expand our communications platforms, we can even track how people are engaging in the Twitter community for AIAA. Crowdsourcing platforms are another great way to measure how many people submit questions or how many people engage in that community. It's kind of like citations in the academic world. On a crowdsourcing platform, you also get your ideas rated, likes and dislikes. All those are great ways for us to get in and track our engagement. What I really want to see is: Are people jumping from a forum where they're talking about some technical subject and breaking out to do public policy and start engaging in those platforms?

Regional and national events >>

I'm really interested in tying the national discussions to the regional discussions. Are the people who participate in the sections getting engaged in some of the national forums as well? That's an area where I'd really like to see the engagement grow. I think a lot of people who want to engage at both levels just run out of bandwidth. We're still going full speed in spite of everything else going on around us. We are continuing to advance our systems, develop new technologies, explore new capabilities in performance. People in our industry work very hard, work very long days. So how much time do you have left after all that, and your families and other responsibilities? Do you have time to engage at both levels? Where AIAA can help is make it easier and being able to have all forums tied together so they're not having to go engage separately. Get them interlinked so that it doesn't take so much of a time commitment. I think that's the only thing holding us back. ★

George Nield *Continued from Page 19*

Building a post-covid world >>

Already we've been successful at being able to engage a much larger number of people in our meetings, in our ceremonies, in our gatherings than we ever could have before. There's always going to be something to be said for the in-person interaction, but I think this is offering us an opportunity to change how we do business, to offer different kinds of products and services, to really accelerate the capability of offering online products and services to people all around the world that we might not have thought about doing before, or at least this quickly. I'm interested in seeing if we can knock down some of those obstacles that are either preventing someone from being a member in the beginning, or we're teaching them a new habit that says, "This is a lifelong learning opportunity." It is an opportunity to help your career and to continue to advance in something that they probably really are interested in, which is why they signed up in the first place.

Moving faster >>

What we're seeing in the world of entrepreneurial activities, in the aerospace community and other areas, is the world is not waiting anymore. If we want to be out there in front of the parade, we're going to have to figure out how to make decisions and implement things more quickly than we've ever done before. It's basically going to come down to lowering the bars of granting permission, of trusting the different parts of the institute. We've got sections, we've got regions, we've got technical committees and program committees and so forth. One of the challenges that the government has had lately is if you try to work your way through bureaucracy, it takes forever, and so there's all these different people at different levels that have the ability to say no to something, but there's nobody that can say yes and have it happen. Maybe not all these ideas are going to work for an organization like AIAA, but I really think we have a lot of flexibility, and so with energy and goodwill among all the participants, if we just consciously decide "we're going to try to do a lot of different things," some of them will work really well, some might need some mid-course corrections, and some of them frankly won't work and that's OK.

Expanding expertise >>

Our technical reputation is first class, and regardless of whether as many people as we think should join actually do, we have a great reputation for doing good work and having high-quality journals and conferences and information. That's great. We don't want to mess with that. At the same time, with new technologies, new discoveries, we might consider how to accommodate new pieces of the puzzle, subjects that we haven't really dealt with in the past, including the whole idea of urban air mobility vehicles or megaconstellations, space traffic management, drones. I know we've been thinking about how AIAA could contribute in those areas for a number of years. There's a lot of work to do, so why shouldn't AIAA be part of writing the standards and working with the government and companies and academia to really make progress in a much more timely fashion?

Building new relationships, strengthening old ones >>

I'd start with entities that we have strong relationships with already. So our AIAA corporate members, is that relationship all that it can be? For instance, why don't we have a full 144,000 people from Boeing? They're in the middle of aerospace; they're building airplanes. They're making spacecraft; they're launching things. We want that whole community, so let's figure out what kind of relationship would be mutually beneficial to the company in terms of giving experience and opportunities to their employees to become leaders and volunteers and make a difference in technical conferences and running papers and so forth, but also to AIAA by having more people in the tent that represent all different parts of aerospace. Next group would be the government entities. People who work for NASA, people who are in the Space Force, people who are employed by the FAA or other similar government organizations have this natural affiliate organization, the AIAA, that they can be a part of. Then there's all kinds of other groups like those for pilots, aircraft mechanics and technicians, hobbyists, people who belong to these other interest groups — those are not professional societies, but they have to do with aircraft and space. There's some potential mutual benefit. Maybe they have access to some of our activities and our products and services, and potentially they become part of our membership pool as well. It can be a real win-win in situations that have previously been competitive: "I only belong to one thing and I have to decide which it is." Let's change our thinking on that.

Measuring impact >>

This is a membership organization, so that's an excellent metric in terms of not only how healthy the organization is, but also what kind of influence it can have and what it can accomplish. We certainly want to be financially responsible, but I think there's a real danger in looking at how much profit are we making or how much do we have in the bank — that to me is not what AIAA is all about. You can measure our impact by the feedback from members and how many members we have; we can measure our influence and impact and success by how often we are asked for our opinion and advice by Congress, by the White House; the kinds of events that we're able to hold internationally and the stature that we are held in in the rest of the world community. All those things are ways to measure our success as opposed to just how much money do we have in the bank.

Building a more diverse AIAA >>

We need to do a better job of gathering information first. I don't think we completely know all the stats on all of our members, but to the extent that we do have data available, a couple things jump out to me. As of now, 91% of AIAA members are male. Nine percent are female. Something's wrong there, so what do we need to do to fix that? It can go back to the pipelines; it can go back to having a welcoming and supportive introduction to the organization at the very beginning, and it doesn't even have to start in college. So how can we make sure they are part of AIAA and that they feel supported and embraced and welcomed in our organization? You can organize it different ways, but to me it all comes back to membership. We want more people, and we want all kinds of people, and how are we going to do that? There might be certain things we do to address having more women members, certain things we do to address having more minorities, certain things we do for young people versus people later in their careers, but that's all part of "how do we reach out to the community and welcome them in the tent?" ★

Scaling up

One of the great remaining accomplishments of flight would be creating an operational aircraft that can fly hypersonically, defined as Mach 5 or above, by gleaning oxygen for combustion from the air, just as conventional jets do. The U.S. has tested air-breathing hypersonic engines, but not of the size required for aircraft that would carry passengers, weapons or intelligence equipment. Jan Tegler looks at the challenges of scaling up.

BY JAN TEGLER | wingsorb@aol.com

▲ An X-51A Waverider undergoes preparatioins for a 2009 captive-carry flight. The U.S. Air Force is aiming to put bigger demonstrators in the air in five years.
U.S. Air Force

The crux of the technical issue facing the Pentagon's hypersonics planners can be seen in old photos of NASA's X-43A demonstrators and the U.S. Air Force X-51A Waveriders. Over the phone, Luca Maddalena, a hypersonic flight researcher at the University of Texas, Arlington, guides me online to one particular image of an X-51A hypersonic demonstrator from 2009. The vehicle is slung under the wing of a B-52H at Edwards Air Force Base in California, just before a captive-carry flight. A researcher has placed his hand near the inlet of the craft's supersonic combustion ramjet, or scramjet, engine, so called because air and combustion gases must whoosh through the engine at supersonic speeds without snuffing the combustion.

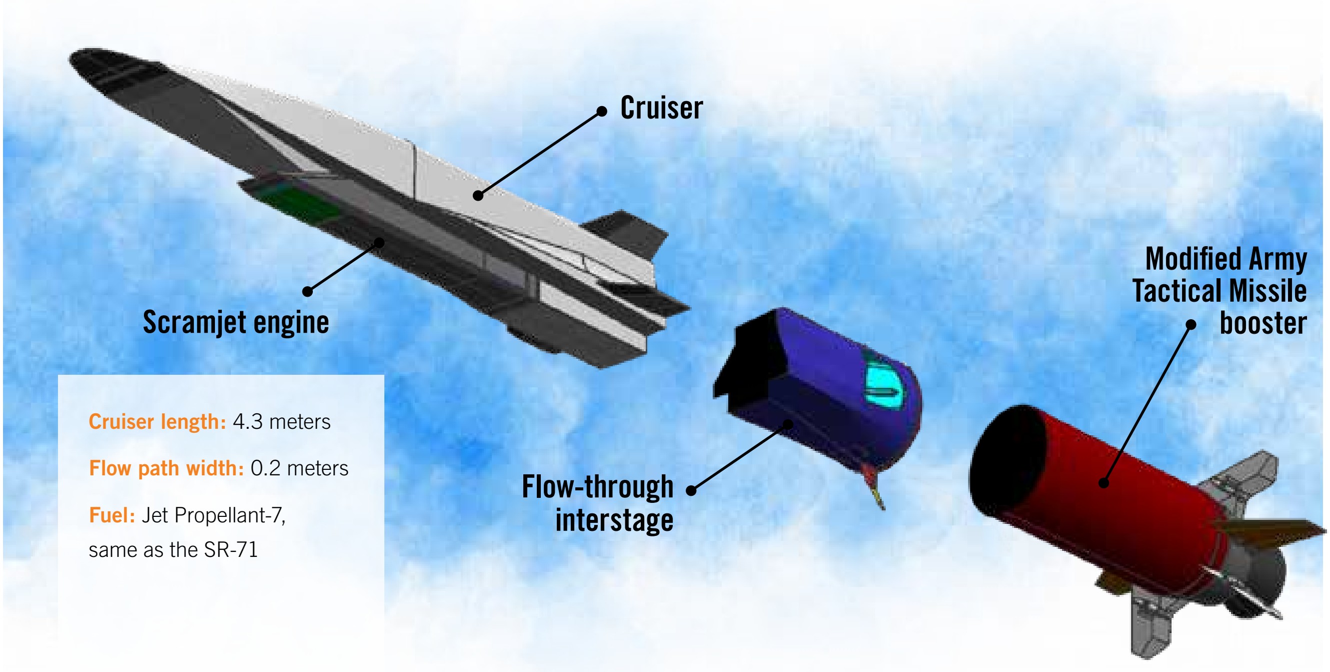
This is what Maddalena wants me to note: "The capture area, the inlet opening, is the size of your hand," Maddalena says.

Each of the four X-51A Waveriders was a small-scale, expendable research aircraft, as were the three NASA X-43A vehicles that flew six years earlier in the Hyper-X program.

Scaling up such designs to carry conventional bombs, cameras and eavesdropping equipment for the military or passengers in the civil context would require a larger inlet to provide more air and therefore oxygen to burn more fuel and generate more thrust. In fact, such an air-breathing engine might need to ingest 10 times more air, depending on the mission, and U.S. military researchers have made this 10X performance a top goal.

Flying free

The decade-old design of the X-51A scramjet engines marks the starting point in the U.S. Air Force's efforts to scale up such air breathing designs by a factor of 10. After separating from their boosters and interstages, the X-51A cruisers proved that supersonic ramjet combustion could be maintained for minutes.



Drawing derived from Boeing, U.S. Air Force documents; research by Cat Hofacker

As with a conventional aircraft, the payoff of an air-breathing design would be greater range and simpler ground support, since the atmosphere supplies an endless amount of oxygen, and there would be no need to compress oxygen into liquid and lug it along. But scaling up raises a host of combustion and mechanical challenges that have yet to be fully addressed in the international race among China, Europe, Russia, Australia, India and the United States to create air-breathing hypersonic missiles, aircraft and space launch vehicles.

Here in the U.S., the Air Force Research Laboratory in Ohio hopes to resolve many of those challenges through a potential new program nicknamed Mayhem for its goal of disrupting the hypersonics status quo. If this Expendable Hypersonic Multi-Mission Air-Breathing Demonstrator Program proceeds, then in five years one or more expendable, air-launched Mayhem demonstrators could be streaking over a test range at over five times the speed of sound, equipped with storage bays capable of carrying three distinct kinds of payloads that AFRL has not specified. The lab would not say whether or how many dollars AFRL has identified for the potential new program in fiscal 2021, but budget documents refer to consolidating dollars under an existing “Next Gen Platform Demo” program element (the documents describe this as a “realignment” rather than a “new start”) and researching scramjet technologies for a “Multi-Mission Cruiser concept.”

It’s not just the U.S. military’s hypersonics advocates who are excited by the possibility of Mayhem. Maddalena, who is not affiliated with the program-in-waiting, wants each Mayhem to be “a flying work bench for academics” and also “government and industry” researchers who have aspirations for building a wide range of hypersonic aircraft, perhaps even commercial passenger versions.

AFRL’s Mayhem information request drew the attention of 30 companies who responded by the late September deadline, including Aerojet Rocketdyne, Lockheed Martin and Northrop Grumman. AFRL says that at this point the Mayhem program is still under development.

Mixing fuel and air

To sense the technical issues, consider that turbine engines and ramjets slow air to subsonic speeds for combustion. By contrast, scramjets have “only a millisecond to mix fuel and air in a combustor” as the air whooshes through the flow path supersonically, Maddalena explains. Getting the fuel-air mix-

Diverse claims to fame

	X-51A	X-43A
BIG ACHIEVEMENT	**Flew for minutes** One of the four expendable demonstrators flew for 3 minutes and 29 seconds at Mach 5 in the program's final flight in May 2013.	**Flew fastest** One of the three expendable demonstrators flew for 10 seconds at Mach 9.68 in the program's final flight in November 2004, setting a record for air-breathing vehicles, according to the 2006 Guinness Book of World Records.
VEHICLE LENGTH	4.3 meters	3.7 meters
PROPELLANT	Jet Propellant-7, same fuel as the SR-71, and oxygen from the air	Liquid hydrogen, same as the space shuttle orbiters, and oxygen from the air
CONTRACTORS	Cruisers and interstages by Boeing Phantom Works; scramjet engines by Pratt and Whitney Rocketdyne (now Aerojet Rocketdyne); modified Army Tactical Missile boosters by Lockheed Martin	Aircraft and engines by Micro Craft Inc. (now part of Northrop Grumman Space Systems); flight control software by Boeing Phantom Works; Pegasus boosters by Orbital Sciences Corp. (now part of Northrop Grumman)
SPONSORS	U.S. Air Force Research Laboratory, DARPA	NASA Aeronautics Research Mission Directorate

Sources: Artist renderings from NASA, U.S. Air Force; research by Cat Hofacker

ture right was tricky enough in the comparatively small scramjets that powered the X-43 and X-51. Doing it in a scaled-up scramjet is "not an incremental problem," Maddalena says. "We've probably been studying mixing for 60-plus years and we don't have an answer."

He asks me to picture a scramjet whose combustor walls are lined with fuel injectors that introduce hydrocarbon fuel into the chamber to mix it with the air rushing by. The bigger the scramjet, the larger its combustor cross-section must be, and if it's too big, the fuel "cannot penetrate deep enough near the center line of the cylinder, so a large portion of the entering air would not be involved in the mixing process," Maddalena says.

Without thorough mixing at the molecular level, combustion cannot be ignited or sustained. Even when combustion can be sustained, "we want the fuel to spread as much as we can so to utilize all the air coming into the engine," which maximizes thrust.

Maddalena says it might be tempting to think you can "photo-scale" an engine — enlarging it like a photograph. "But unfortunately, the fluid dynamics of turbulent mixing does not photo scale."

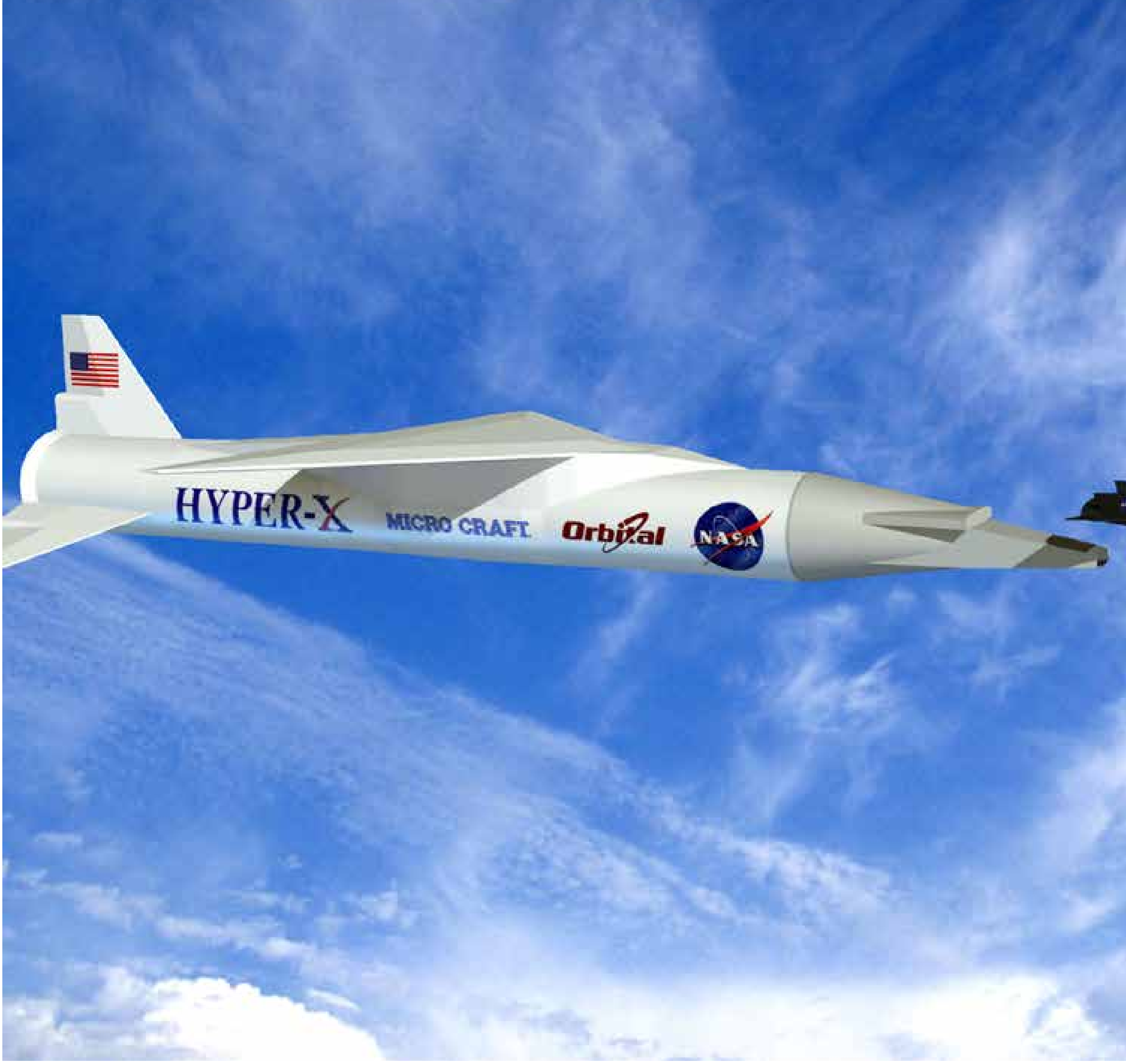
He suggests that corporations and the U.S. government involve university researchers more than they have so far on mixing and other scalability issues.

Research to date

There could well be more to learn, but if Mayhem proceeds and requires a scaled-up scramjet, engineers won't be starting from zero on the fuel-air mixing problem and other challenges of scaling up. Last month, Aerojet Rocketdyne reported generating in excess of 58 kilonewtons of thrust, enough, the company says, to accelerate "a vehicle approximately 10 times the size of" the X-51A. A rival design by Northrop Grumman also generated

▲ **A U.S. Air Force B-52** Stratofortress carries an X-51A Waverider before the scramjet's first hypersonic flight test in 2010.

U.S. Air Force



about 58 kN of thrust in 2019 during tests at the Air Force Arnold Engineering Development Complex in Tennessee under the same Medium Scale Critical Components program.

For comparison, the X-51A scramjets (built by Rocketdyne when it was part of Pratt and Whitney) generated a maximum of 4.4 kN of thrust. At 5.5 meters long, the new engines are about seven times longer than the X-43A engines and also significantly longer than the X-51A engines, although the Air Force would not provide a precise length. Because of the Arnold experiments, "the government is confident in our ability to design" scramjets "at any scales," says AFRL's Edgardo Santiago-Maldonado, whose portfolio as the lab's next-generation hypersonic lead includes scramjet testing. In Maddalena's view, the "chapter on scalability, from a scientific perspective, is not yet closed as it requires much more work and understanding." But there's no doubt the results of the MSCC program are "exciting" and "constitute a very significant contribution to the scalability challenge."

Alternative architecture

Bigger engines aside, there may be a way around the scaling problem. "You could potentially take something that was the size of the X-51 engine and just put three of them on a vehicle," says NASA's Chuck Leonard, who manages NASA's Hypersonic Technology Project. Researchers under that effort are investigating concepts for hypersonic aircraft that would be powered by turbine-based combined

▲ **An X-43A research** vehicle separates from a Pegasus booster in a screen shot from a NASA animation.
NASA

Scaling up raises a host of combustion and mechanical challenges that have yet to be fully addressed in the international race to create air-breathing hypersonic missiles, aircraft and space launch vehicles.

cycle engines that would include a turbine-ramjet-scramjet cycle. The problem of scramjet scalabilty also applies to these TBCC concepts.

"Maybe you can put multiple smaller engines on it, what we sometimes call modules," Leonard says.

There would be a host of structural considerations to be evaluated, but "at least you could fully test that X-51-size engine on the ground," he says, alluding to the few American wind tunnels capable of testing larger scramjets.

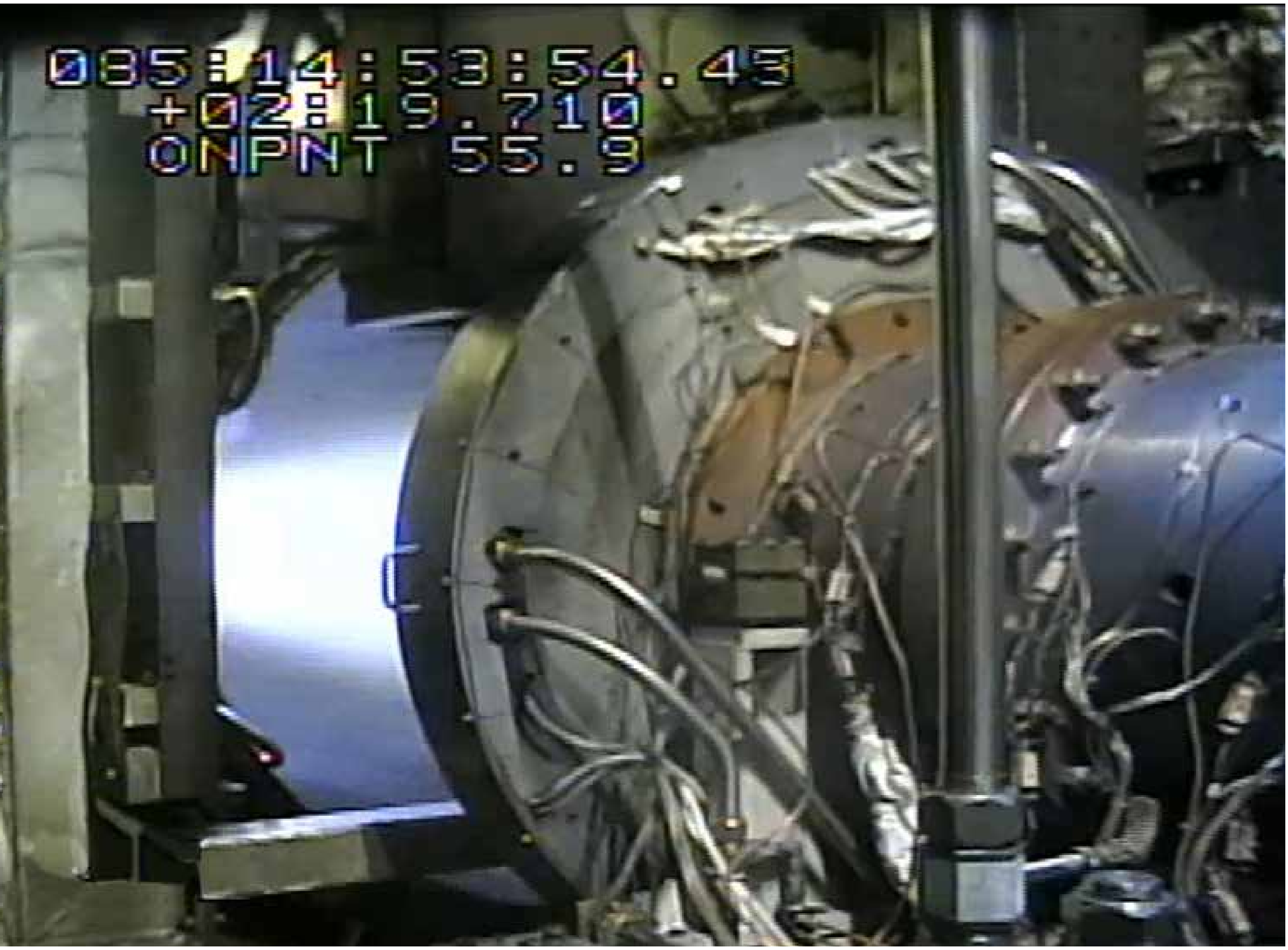
Testing smaller engines might help researchers gain an understanding of the tradeoffs between one larger engine or multiple engines, although fully grasping the advantages and drawbacks would require creating a "whole-vehicle concept," he adds.

DARPA's contribution

DARPA, as part of its Advanced Full Range Engine program, has been examining the challenges of creating a larger scramjet engine capable of propelling payload-carrying aircraft at hypersonic speed.

The goal is platform scale propulsion, meaning an engine capable of propelling an aircraft. By contrast, weapons scale would be "something smaller that would drop off a wing," explains Nathan Greiner, who manages the program.

Aerojet Rocketdyne with Lockheed Martin as a subcontractor, is working with DARPA on the program, aiming to demonstrate the individual components that make up a TBCC engine at aircraft scale. "We've executed tests for the inlet, the turbine



and for the nozzle, and we're leading into testing on the dual mode ramjet in the near future," Greiner explains.

Greiner says each of the TBBC components "have their own challenges with respect to scaling."

He describes the challenge of scaling the TBCC engine's common inlet and nozzle as "tractable" but says the challenge grows as scale grows. As an example, he cites "the actuation required to modulate the inlet geometry and maintain operability over a wide range of Mach numbers."

Changing the geometry inside the inlet by moving a series of surfaces (NASA's Leonard calls them "flaps") in a timely fashion directs airflow to the turbine, ramjet and scramjet at the right moments as the aircraft accelerates or decelerates. The inlet surfaces or flaps also control the speed of the airflow being funneled to the different engines by creating shockwaves that slow airflow to subsonic velocity for the turbine and ramjet or allow it to flow at supersonic speed for the scramjet.

"Actuating the variable inlet surfaces at aircraft scale with flight-weight actuators is very challenging and requires intense engineering," Greiner says.

No one I interviewed could say for sure whether the Northrop Grumman and Aerojet Rocketdyne engines, NASA's research on engine modules or DARPA's work on variable inlets will make it into the Mayhem program, if the Air Force indeed starts it. But the research to date has given contractors new confidence about the propulsion challenges.

Raymond Toth, who leads Northrop Grumman's Advanced Propulsion and Control Systems business strategy team, points to the engine his company tested in Tennessee. "Given a desire by the Department of Defense to put a scramjet of that size into a system and given the right investment we think we could bring something like that to a flight stage within the next five years," he says.

The question he says, "is what is the vehicle that it's going to fly in?" ★

▲ **This Aerojet** Rocktdyne engine generated approximately 58 kilonewtons of thrust during tests in a wind tunnel at the Arnold Engineering Development Complex in Tennessee, the company announced last month. The engine could accelerate a vehicle 10 times larger than the X-51A, the company said.
Aerojet Rocketdyne

Putting our minds to space travel

Virgin Galactic is getting ready to send its first paying customers to the fringes of space. NASA and European space leaders are talking about establishing a Moon Village for scientists, miners and tourists. Elon Musk famously wants to establish colonies on Mars. What kind of psychological training will people need for these and other bold endeavors? **Sarah Wells** spoke to psychologists and a space travel veteran to find out.

BY SARAH WELLS | sarahes.wells@gmail.com

As the rockets underneath the Soyuz TMA-9 capsule began to warm and hum in anticipation of liftoff, Anousheh Ansari remembers feeling eerily calm. It wasn't until the capsule had torn through Earth's atmosphere and reached orbit that Ansari began to cry.

"It was overwhelming and a rush of emotions — excitement, extreme joy and wonder took over — and I went from crying to laughing to crying to laughing."

Unlike the cosmonaut crewmates grasping her hands during liftoff, Ansari, who is now the CEO of X-Prize Foundation, had not spent years training for her flight. She made the journey to the International Space Station in 2006 after just six months of training and securing a $20 million ticket. She was the world's fourth "space tourist."

At the time, Ansari's and other missions in the early 2000s looked like the start of a bright future for space tourism, but 14 years later that dream has yet to come to fruition, due in part to technical setbacks.

Now, suborbital flight companies Blue Origin and Virgin Galactic are closing in on sending the first paying customers on jaunts to the fringes of space, developments that could serve as a springboard to even bolder space tourism endeavors, such as the orbital tourism plans of SpaceX and Axiom Space.

Courage and money alone are not all that these pioneering space tourists will need for these first flights and the journeys to orbit and deep space that could follow. They'll need varying degrees of psychological preparation not only for safety but to get the most out of the hundreds of thousands of dollars they'll spend on the experience.

For space travel, "psychological and physical preparedness are equally important."

— Space psychologist Raphael Rose

"Psychological adjustment in many ways is harder to identify and can be something that people try to keep to themselves," says space psychologist Raphael Rose, associate director of the Anxiety and Depression Research Center at the University of California, Los Angeles. For space travel, "psychological and physical preparedness are equally important," he says.

Stressors

With the chance to visit space — or even just graze the top of Earth's atmosphere — comes an opportunity many wait a lifetime for, though the experience won't be without its mental challenges.

For professional astronauts, such as the astronaut corps of NASA and the European Space Agency, tension can spring from the pressure to complete mission tasks as well as the reality of being confined in a cramped space with others for extended periods. Astronauts sometimes release tension in the form of terse exchanges with ground control as a tactic to avert tension with fellow crew members during missions that can run days, weeks or months, says psychiatrist Nick Kanas, who has spent decades studying the impacts of space flight for NASA, and is now an emeritus professor of psychiatry at the University of California, San Francisco.

For tourists on suborbital flights, Kanas expects that kind of tension to be minimal to nonexistent, given the brevity of the experiences. Blue Origin's proposed time in the capsule will clock in at 41 minutes, including 30 minutes of boarding time and four minutes of weightlessness, while Virgin Galactic's is approximately 1.5 hours with a similar amount of weightless time. At its worst, customers might feel like they are stuck in an elevator with work colleagues for an hour. This is a discomfort that Kanas suggests could be easily tolerated.

That said, with customers paying up to $250,000 for the experience of weightlessness and the view of Earth from an altitude of about 100 kilometers, a wild card remains the reactions of those customers should a mission not unfold exactly as planned. For example, last month's Virgin Galactic suborbital test flight was cut short moments after the release of the VSS Unity spaceplane from the WhiteKnightTwo carrier aircraft, when Unity's flight computer lost its data connection to its hybrid rocket motor, prompting the computer to end the ignition sequence. The two pilots maneuvered Unity for a glided landing at Spaceport America in New Mexico.

Ideally, customers would be prepared enough through their training programs to adapt to any changing circumstances, but Kanas says that there's always a risk — albeit rare — in space travel of having a negative reaction.

"You're worried about somebody reacting with

maybe palpitations or heart pressures, a heart attack of some kind or stroke [or] becoming acutely psychotic," says Kanas. However, these are concerns associated more with orbital flights, which are further from reality, and are conditions that would hopefully be discovered by a psychological screening before the customer ever left Earth.

Also, tourists won't have the stress of operating the vehicle. Rather, they'll have to be comfortable trusting their fates to automated software. Unlike Ansari who was involved in the ascent and descent procedure of her flight and completed science experiments on the ISS, suborbital tourists will just be along for the ride. Blue Origin's New Shepard suborbital rocket and capsule would complete flights autonomously, and instead of pilots onboard with passengers, ground controllers would intervene should the need arise. For a slightly more human touch, Virgin Galactic's Unity will be operated by two professional pilots.

Orbital experiences would be a different matter. Such flights would not necessarily take tourists much higher than suborbital flights, but by going faster, 28,000 kilometers per hour versus 6,000 kph for suborbital flights, orbit could be maintained for days or weeks. Customers on those flights may include academics or visiting scientists who, like Ansari, would have a little more work to do when they've reached their final destination, such as Axiom Space's proposed space station. [See Page 10.]

Kanas is still not too concerned about the mental impact of these longer flights, but he does stress that mental preparation — in addition to physical preparation — will be even more important during such flights to ensure tourists remain calm for the duration.

▲ **Anousheh Ansari,** in white, spent nine days on the International Space Station in 2006 after six months of training and paying $20 million.
NASA

▲ **Virgin Galactic** says its passengers will be able to look out 12 cabin windows, and 16 cameras will record their experiences on video and stills. The illustration shows the cabin interior that the company says is roomy enough for travelers to enjoy the experience of weightlessness.
Virgin Galactic

Mentally training

As far as I could learn, orbital tourism companies do not yet have concrete training plans, although Space Adventures, the spaceflight company that will run SpaceX's orbital tourism programs, does say its training will likely be a few weeks long, and Axiom Space estimates its at 15 weeks. Kanas speculates that these programs may be scaled back versions of what NASA astronauts experience before flying to the ISS.

Tom Jones, a former NASA astronaut who spent a total of 53 days in space, tells me that when he was training for his space shuttle flights in the mid-1990s the crew spent extensive time training together in stress-inducing scenarios, like wilderness exploration, in order to learn how to work together in trying times.

"If you find out somebody has the personality where they become self-centered or withdrawn, it's important to find that out back here on Earth in an analog situation so that you don't send the person up to space for six months where they make life miserable for everybody else," says Jones.

This preparation is why in the past 20 years of sending astronauts to ISS, the number of times an astronaut has exhibited such behavior can be counted on one hand.

A modified version of this NASA training might last a matter of weeks, just as Space Adventures and Axiom are planning. Training for suborbital flights would be much shorter. Virgin Galactic and Blue Origin have both clocked their training programs between two and three days. The exact preparation of each program varies, but generally includes physical training in the form of zero-gravity experiences and familiarization with the cabin and automated procedures.

Virgin Galactic also plans to give its customers comprehensive medical evaluations to identify vulnerabilities that might put them or others at risk during the flight, which may include conditions like claustrophobia or poor stress management. But whether these conditions would ultimately disqualify tourists from flying is not yet certain.

Kanas speculates that space tourism companies will have softer guidelines when it comes to psycho-

> "If you find out somebody has the personality where they become self-centered or withdrawn, it's important to find that out back here on Earth."
>
> — Tom Jones, former NASA astronaut

logical screening than do government space programs. Instead of potentially grounding someone with bipolar disorder because they may have had a manic episode in the past, Kanas suggests that participants with otherwise disqualifying psychological disorders could be given care plans to follow that would ensure their safety and that of others on the excursion.

As a result, Kanas believes the risk of seriously causing harm to fellow tourists out of ignorance of zero-gravity procedures or poor stress management is unlikely for short suborbital flights.

If a passenger were to go rogue and attempt to, for example, pry open the spacecraft door, those actions still won't put other tourists in harm's way. Virgin Galactic tells me that because of pressure created against the spacecraft's plug door, the term also applied to the doors on commercial airliners, it isn't possible to open the spacecraft midflight.

Beyond orbital flight

Space tourists in the next five to 10 years will not be straying too far from home, but if the plans of government leaders and entrepreneurs come to fruition over the nex 20, 50 or 100 years, the space tourism playground would expand far beyond Earth's orbit. Both ESA and NASA have announced their concepts for establishing a Moon Village in the next decade that would function as a mining base and potential tourist destination, and — who knows? — maybe 200 years from now as a retirement destination for those who want to try low-gravity golf. In the far term, Elon Musk tweets regularly about establishing colonies on Mars with transportation provided by his Starship spacecraft, versions of which SpaceX engineers are building and flying at the company's test site in Boca Chica, Texas.

And while today's space tourists are unlikely to experience much psychological distress on their short trips, with longer flights such as a seven-month journey to Mars comes the heightened risk for negative psychological effects, such as depression, as a result of extended social isolation and loneliness, explains space psychologist Rose. For the past 12 years, Rose has conducted research with NASA on stress, resilience and behavioral health and is principal investigator on two ongoing NASA projects, one titled "Asynchronous Behavioral Health Treatment Techniques."

Developing a therapeutic plan that can work even with the communications latency of deep space will be crucial for the well-being of these explorers, says Rose.

"We developed a stress management resilience training program that autonomously trains people

to develop a tool set of skills they can use to deal with stressful situations," explains Rose. He defines resilience as "a rebound and recovery" from stress, "not an elimination of stress."

During these longer trips, Rose says individuals must be provided with tactics for managing their own stress when professional counselors can't be on hand to help. Crew bonding activities will help, but connections must somehow be maintained with family and friends, perhaps through memories, when communications with Earth become intermittent.

"Thinking about their family or other things in their community that provide meaning to them can help them feel more connected," Rose says.

Rose imagines that someday artificial intelligence and virtual reality software might simulate a traveler's home and generate realistic and interactive projections of loved ones that they could communicate with. Solutions like this won't irradicate the potential stress of the situation, but they can provide a better way to cope with it.

"Stressful reactions to stressful situations is expected," says Rose. "There isn't a magical way to do something that's challenging and not feel stress — that's not a bad sign. It's more about how you cope with these situations that make a difference."

Positive effects of space travel

Space tourists who have paid hundreds of thousands of dollars for a once-in-a-lifetime experience will likely want to maximize the positive psychological effects of this foray to space. In fact, Loretta White-

▲ **The European Space Agency** runs a three-week course in which astronauts explore caves while testing technology and conducting experiments in order to prepare them for the rigors of space travel. Astronauts from space agencies around the world participate.
ESA

sides, the wife of Virgin Galactic Chief Space Officer George T. Whitesides and author of the book "The New Right Stuff: Using Space to Bring out the Best in You," believes that someone who pays to go to space can return a new person. Whitesides herself is a "founder astronaut" at Virgin Galactic, meaning she will be one of the first several participants to ride in Unity when commercial service begins.

In her space training and consultation program, SpaceKind, Whitesides coaches space industry professionals about how to embrace vulnerability, humility and integrity in order to bring their best selves to their future space travels. Whitesides believes that leaving your personal baggage at home is crucial to fully experiencing the beauty of space and the fragility of Earth. Astronauts have widely described looking down on Earth as a spiritual and unique experience that transformed them into more charitable versions of themselves upon return.

This "overview effect" is something that Ansari and Jones both say they experienced during their travels.

"Being in space has made me feel the interconnectedness of us human beings with each other and our planet," says Ansari. "As the world shrunk in front of my eyes in my ascent to orbit, so did the problems of the world. This new perspective has made me more hopeful than ever that we can solve the problems that seem so big and overwhelming."

In the future, Kanas muses that the overview effect may even be prescribed as a form of treatment for Earthly ennui, similar to a therapeutic retreat today.

▲ **European Space** Agency astronauts joined their Chinese counterparts for nine days of survival training off China's coast in 2017. They practiced jumping into inflatable lifeboats from a mock Shenzhou capsule and being hoisted aboard a rescue ship.
ESA

Whitesides believes that creating the right mindset for space travelers to receive this experience can enable space tourists, professional astronauts and everyone in between to return home with a new mission to be more generous on both a personal and community level.

SpaceKind is not likely to be mandatory for space tourists, says Whitesides, but she believes that programs like these could be offered as a la carte options that tourists can choose to take for their own benefit.

"Most of them are so passionate about space — like a lot of my fellow 'future astronauts' at Virgin Galactic [who do extra training] because that's what we like to do," says Whitesides. "I'm counting on the customers to go even beyond what's required."

Where are we now

When it comes to preparing future space tourists for the mental and physical rigor of spaceflight, Kanas and Rose say that the No. 1 mindset that must be imparted on trainees is a sense of familiarity with the spacecraft and mission plan, as well as assurance of its safety.

This is something that Virgin Galactic is focusing on heavily in its Astronaut Readiness Program in which its ticketed future astronauts will gain detailed information about Unity, even down to its sounds and smells. Separate from SpaceKind, this three-day program was announced in 2019 and is led by former NASA engineer Beth Moses.

The company also announced a contract with NASA last year to develop a separate "private orbital astronaut readiness program" to help NASA meet its goal of increasing commercial use of the ISS by finding and training private spaceflight participants.

Ultimately, says Kanas, regardless of what these training programs entail, this industry is going to continue expanding. Where space travel exists, there will never be a shortage of space tourists.

"There's always some population that's willing to do anything, so I don't think that's going to slow down things," says Kanas. He says it is more a question of "the technology of getting this thing up safely and get it back down again." ★

Staff reporter Cat Hofacker contributed to this report.

OPINION

Why we're not there yet on CFD

The fundamental mathematics that aircraft designers rely on to model fluid mechanics, the Navier-Stokes equations, were devised in the 19th century. This set of partial differential equations seems tantalizingly straightforward, yet many challenges remain today in realizing an accurate predictive capability. Stephen M. Legensky, founder of the software company Intelligent Light, explains.

▲ **Rotorcraft** computational fluid dynamics rendered by FieldView.
Intelligent Light

BY STEPHEN M. LEGENSKY

In my journey as the founder and leader of Intelligent Light, I have had the privilege of meeting some of the pioneers of CFD through our visualization and knowledge-extraction software products. These visionaries freely shared their valuable time, answering my naïve questions and helping me to understand their field and how our tools might help the CFD community. In the late 1980s, United Technologies Research Center used our 3DV software to produce animations of CFD results by converting them into formats that could be rendered and recorded to video tape. Thus began my adventure and a great opportunity for Intelligent Light through our FieldView software, which has helped countless engineers visualize and model aircraft performance by solving the Navier-Stokes equations, the fundamental mathematics for modeling fluid dynamics that were devised in the 19th century. As powerful as the FieldView tool remains under its new owner, FieldView CFD Inc., much innovation remains ahead to fully tap the potential of applying the Navier-Stokes equations for modeling aircraft in flight.

So why are the Navier-Stokes equations so difficult to tame? Unlike static structural analysis and other physical modeling regimes, the Navier-Stokes formulae are partial differential equations that for most interesting geometries and realistic flow conditions, do not have an analytical solution. You can't just plug algebraic terms into the Matlab software and get an answer. Numerical methods for solving these equations have been under development for more than a half century. The fundamental idea for the most popular methods is to discretize the flow domain around or within the object under study: The physical space is divided into cells as small as a millimeter on a 747-scale aircraft. Time is also broken down into very small timesteps, sometimes on the order of microseconds or even nanoseconds.

Solution methods with names like Finite Difference, Finite Volume, Finite Element and Direct Numerical Simulation are then applied to the millions or billions of cells, timestep by timestep. (Techniques such as Lattice-Boltzmann, Particle-in-Cell and Smooth Particle Hydrodynamics are also used, but tend to have more specialized applications.) Each of these methods has advantages and disadvantages in terms of memory needs, computing power requirements, stability (meaning: do we get an answer or a program crash) and most importantly, accuracy.

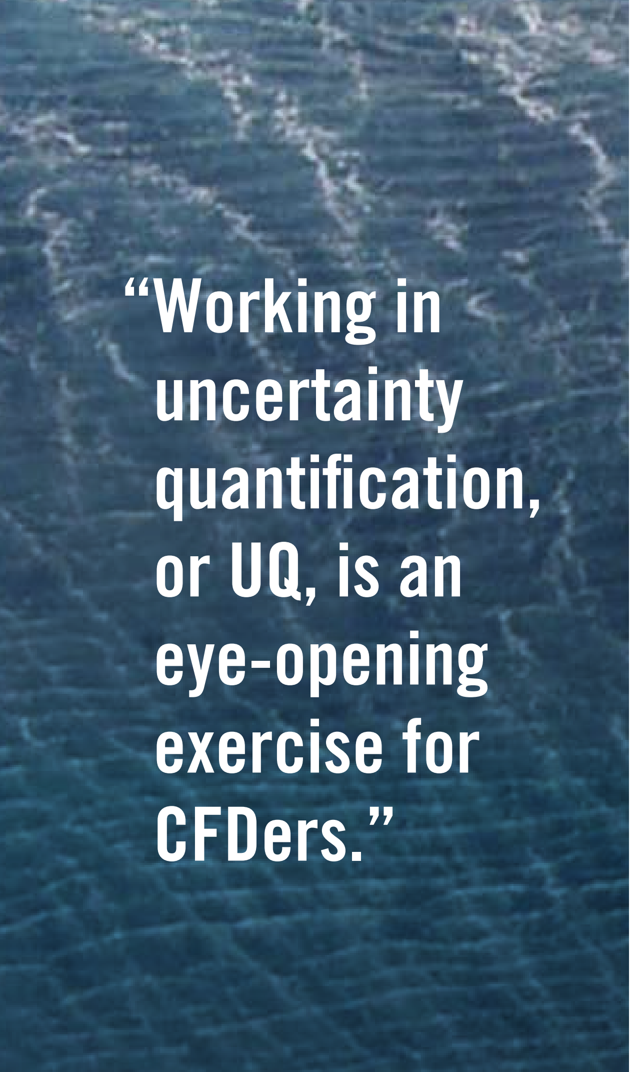
Solving differential equations has another important requirement: boundary conditions. For example, what is the speed of the airplane or the temperature and pressure at the inlet of a jet engine combustor? These conditions are natural to us in the real world but expressing them accurately as inputs to the solution program (known as the solver code) or even measuring them accurately, can be very challenging. Even if we could manage boundary conditions, discretization and solution method, there is a trade-off between what can be directly solved and what needs to be modeled. Turbulence, the tendency for many flows to exhibit an almost chaotic behavior, exists at many scales and directly impacts lift and drag, supersonic combustion and other phenomena. The quest to understand and model turbulence has been an ongoing pursuit for more than a century.

Moving to uncertainty quantification

Where are we today with CFD and its application to real-world problems? For many years, engineers applied CFD most often to analyze performance trends due to design changes, rather than as a quantitative, predictive tool. If my airplane was not behaving as I expected, CFD might be used to simulate the flow, computing the velocity in each cell in three dimensions around my vehicle so that, with the appropriate software, I could visualize the flow field. If the cause of the problem could not be located, a change could be made to the shape of the wing and then another calculation would be performed. This was probably much less expensive than modifying the actual aircraft and testing in flight.

Quantitative results could be expected only for certain situations that were well understood with well-behaved designs, such as an aircraft with smooth flight surfaces operating at cruise conditions. These predictions were very important for estimating the fuel efficiency of a new vehicle and identifying the design that was the best compromise. Airframers have been refining the tools and processes for this kind of application for years, but these revisions still do not cover more demanding scenarios. You see, these traditional calculations apply to airplanes that are deliberately shaped to avoid the types of fluid mechanics phenomena that plague CFD even to today: flow that separates from the flight surfaces and might possess unstable vortex behavior. In such cases, the physics of the flow can reveal the shortcomings in the solver code, discretization and turbulence model. But, if you do not know the correct answer for a new design, how does one know if the calculations are truly predictive?

This is where the field of uncertainty quantification comes in. Over the past decades, UQ has gained prominence as a way to understand and to quantify the reliability of analysis predictions. The simplest way to understand the role of UQ is that it provides a rigorous statistical framework to incorporate experimental data, variations in CFD methodologies and boundary conditions into the analysis process. Rather than just stating that the predicted drag will be 107 under particular conditions, the engineer is provided with what are called "confidence intervals"



that might read like: "Within a 95% confidence level, the drag is predicted to be between 104 and 110." Currently, the UQ process can be computationally and experimentally expensive, since instead of doing one simulation with fixed boundary conditions or turbulence models, many such computations are needed to create the statistical picture of the simulation certainty. Creating efficient workflows for UQ is certainly a topic of extensive research today. Intelligent Light has been funded in this area by the U.S. Department of Energy, whose DAKOTA software is the gold standard for UQ and optimization.

Increased precision

Working in UQ is an eye-opening exercise for CFDers. Several sources of uncertainty have been identified in the CFD workflow: discretization, model form and boundary conditions are a few. What were once accepted as good enough are no longer: If you really want to predict the behavior and performance of brand new concepts or you want to understand flow regimes that are not well behaved, then, in reality, the status quo is not good enough. In general, the precision of the discretization has to be increased in order to truly capture the object's shape and perhaps the turbulent scales. In the emerging concept of the digital twin, geometry is modeled as built, rather than from the idealized computer aided design. Then the boundary conditions need to more closely approximate the real world: Is the Mach number truly exactly 0.85, or is it between 0.82 and 0.87, and subject to some probability distribution? Finally, there are the numerical modeling issues: Are there compromises in the methods of solving the differential equations and handling turbulence? All of this co-exists with limitations on computing resources, solver performance, the workforce and even the ability to gather useful ground truth from tests.

The CFD development community is vibrant today and actively developing new technologies to improve the robustness, accuracy and efficiency of codes that use the various numerical methods. NASA funded an effort to set goals for CFD in the year 2030 and a report was published in 2014. These goals have brought focus to advancing the areas of solver methodology, discretization, turbulence modeling, UQ and also knowledge extraction. An update is due for publication at AIAA's SciTech 2021 and the reader is referred to that white paper for the technical details of the progress being made and the teams that are advancing toward the goals.

For our part, Intelligent Light has been playing a supporting role for the CFD community, focused on UQ, knowledge extraction and data science applications for CFD. One of the problems with the increase in fidelity and the number of simulations is data size. Although supercomputing has scaled in performance by orders of magnitude over the decades, we humans have not. Two interesting aspects of work in this area are extract workflows and solution interpretation guided by data science techniques. Extract workflows attempt to get the most meaningful portions of a CFD solution directly from the solver memory into a compact useful form. Data science techniques, either modal analysis or machine learning, can help to find patterns or coherent structures within the sea of raw data.

It should be clear at this point that CFD, a field of study with a rich history, still has many opportunities for improvement. I am confident that the dedicated practitioners out there in the world will continue to push the boundaries of the technology for years to come. At the same time, machine learning is making strides to complement the current state of the art. I read in MIT Technology Review about a deep learning technique developed at Caltech that can solve families of partial differential equations such as Navier-Stokes a thousand times faster than traditional methods. Stay tuned. ★

Stephen M. Legensky founded Intelligent Light in 1984 and remains president and chief technology officer. He helped grow the company from a producer of 3D animations to a leading supplier of tools for CFD workflow and UQ. He has a bachelor's degree in engineering and a master's degree in mathematics from Stevens Institute of Technology in New Jersey.

AIAA Bulletin

DIRECTORY

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

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

Calendar

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2021			
9–10 Jan	5th AIAA Propulsion Aerodynamics Workshop (PAW05)	ONLINE (http://learning.aiaa.org)	
10–12 Jan	AIAA International Student Conference	VIRTUAL EVENT	
11-15 & 19-21 Jan	AIAA SciTech Forum	VIRTUAL EVENT	8 Jun 20
21–22 Jan	1st AIAA CFD Transition Modeling Prediction Workshop	ONLINE (http://learning.aiaa.org)	
26–27 Jan	1st AIAA Stability and Control Prediction Workshop	ONLINE (http://learning.aiaa.org)	
28 Jan–4 Feb*	43rd Scientific Assembly of the Committee on Space Research & Associated Events	Sydney, Australia —HYBRID EVENT (cospar2020.org)	14 Feb 20
31 Jan–4 Feb*	31st AAS/AIAA Space Flight Mechanics Meeting	VIRTUAL EVENT (http://space-flight.org)	
26 Feb–16 Apr	Design of Experiments: Improved Experimental Methods in Aerospace Testing Course	ONLINE (http://learning.aiaa.org)	
4 Mar–28 Apr	Fundamentals of Classical Astrodynamics and Applications Course	ONLINE (http://learning.aiaa.org)	
6–13 Mar*	2021 IEEE Aerospace Conference	VIRTUAL EVENT (www.aeroconf.org)	
15–19 Mar	AIAA Congressional Visits Day	VIRTUAL EVENT	
18 Mar–8 Apr	Hypersonics: Test and Evaluation Course	ONLINE (http://learning.aiaa.org)	
24 Mar–14 Apr	Technical Writing Essentials for Engineers Course	ONLINE (http://learning.aiaa.org)	
26–27 Mar	AIAA Region III Student Conference	Ann Arbor, MI	5 Feb 21
26–27 Mar	AIAA Region IV Student Conference	Stillwater, OK	1 Feb 21
2–3 Apr	AIAA Region V Student Conference	Iowa City, IA	21 Feb 21
3–4 Apr	AIAA Region VI Student Conference	Long Beach, CA (VIRTUAL)	6 Feb 21
6–8 Apr*	AIAA SOSTC Improving Space Operations Workshop	VIRTUAL EVENT (https://isow.space.swri.edu)	
6 Apr–13 May	Design of Space Launch Vehicles Course	ONLINE (http://learning.aiaa.org)	
7–16 Apr	Fundamentals of Data and Information Fusion for Aerospace Systems Course	ONLINE (http://learning.aiaa.org)	
8–9 Apr	AIAA Region II Student Conference	Tuscaloosa, AL	23 Feb 21
9–10 Apr	AIAA Region I Student Conference	New Brunswick, NJ	19 Feb 21
9, 16, 23 Apr	Understanding Space: An Introduction to Astronautics and Space Systems Engineering Course	ONLINE, 3 full days (http://learning.aiaa.org)	

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.).

12–14 Apr*	55th 3AF Conference on Applied Aerodynamics (AERO2020+1)	Poitiers, France (http://3af-aerodynamics2020.com)	
13–29 Apr	Fundamentals of Python Programming with Libraries for Aerospace Engineers Course	ONLINE (http://learning.aiaa.org)	
14– 30 Apr	Missile Aerodynamics, Propulsion, and Guidance Course	ONLINE (http://learning.aiaa.org)	
15–18 Apr	AIAA Design/Build/Fly Competition	Tucson, AZ	
19 Apr	Directed Energy Professional Society Symposium, in coordination with AIAA DEFENSE Forum	Laurel, MD	
20–22 Apr	AIAA DEFENSE Forum	Laurel, MD	17 Sep 20
20–22 Apr*	Integrated Communication, Navigation, and Surveillance (ICNS) Conference	VIRTUAL EVENT (https://i-cns.org)	
5–7 May*	6th CEAS Conference on Guidance Navigation and Control (2021 EuroGNC)	Berlin, Germany (https://eurognc2021.dglr.de)	
5–28 May	Electrochemical Energy Systems for Electrified Aircraft Propulsion: Batteries and Fuel Cell Systems Course	ONLINE (http://learning.aiaa.org)	
7, 14, 21 May	Foundations of Model-Based Systems Engineering (MBSE) Course	ONLINE, 3 half days (http://learning.aiaa.org)	
31 May–2 Jun*	28th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (elektropribor.spb.ru/en)	
5–6 Jun	3rd AIAA Geometry and Mesh Generation Workshop (GMGW-3)	Washington, DC	
5–6 Jun	4th AIAA CFD High Lift Prediction Workshop (HLPW-4)	Washington, DC	
5–6 Jun	1st AIAA Ice Prediction Workshop	Washington, DC	
6 Jun	2nd AIAA Workshop for Multifidelity Modeling in Support of Design & Uncertainty Quantification	Washington, DC	
7–11 Jun	AIAA AVIATION Forum	Washington, DC	10 Nov 20
21–23 Jun*	3rd Cognitive Communications for Aerospace Applications Workshop	Cleveland, OH (http://ieee-ccaa.com)	
22–25 Jun*	ICNPAA 2021: Mathematical Problems in Engineering, Aerospace and Sciences	Prague, Czech Republic (icnpaa.com)	
9–11 Aug	AIAA Propulsion and Energy Forum	Denver, CO	11 Feb 21
17 Aug	AIAA Fellows Dinner	Washington, DC	
18 Aug	AIAA Aerospace Spotlight Awards Gala	Washiington, DC	
6–10 Sep*	32nd Congress of the International Council of the Aeronautical Sciences	Shanghai, China (icas.org)	15 Jul 19
13–15 Sep*	3rd IAA Conference on Space Situational Awareness (ICSSA)	Madrid, Spain (http://reg.conferences.dce.ufl.edu/ICSSA)	15 Jun 21
25–29 Oct*	72nd International Astronautical Congress	Dubai, UAE	
15–17 Nov	ASCEND Powered by AIAA	Las Vegas, NV	

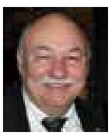
● AIAA Continuing Education offerings

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

2021 AIAA Sustained Service Award Winners Announced

AIAA is pleased to announce the winners of the 2021 Sustained Service Awards, which recognize sustained, significant service and contributions to AIAA by members of the Institute.

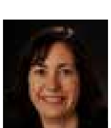
Willem A. Anemaat
DARcorporation
For your extensive service to AIAA through your work on technical committees, national awards, publications, and conferences.



Kevin Burns
American Legion
For sustained and dedicated service to the AIAA History Committee, San Diego Section, Niagara Frontier Section, AIAA conferences/forums, and decades of mentorship to students from universities across the country.

Terry J. Burress
Lockheed Martin Aeronautics
For continuous and exemplary service to the AIAA South Central Region and the Modeling and Simulation Technical Committee, including strengthening the membership and the technical excellence of the Institute and its committees in both formal and informal leadership roles.

Dean Earl Davis
For his 46 years of active AIAA contributions from college chairman to LA-LV Section and STEAM chairman.

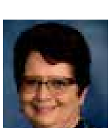


Jeanette L. Domber
Ball Aerospace
Honoring over 15 years of inspiring leadership and dedicated service to the SDM Conferences, AIAA SciTech Forums, Aerospace Design and Structures Group, and Structures Technical Committee.

Mat French
Northrop Grumman
In recognition of his service to AIAA for the creation, development, and leadership of the Digital Engineering Integration Committee (DEIC), a transformational enabler for the aerospace technical community, and for his sustained leadership of AIAA SciTech and CASE sessions.

John. C. Hsu
California State University, Long Beach
In recognition of his contributions to multiple AIAA technical committees, and coordination of conference sessions, publications, and short courses over three decades of exemplary service to AIAA, most notably to the Systems Engineering Technical Committee.

Michel D. Ingham
NASA Jet Propulsion Laboratory
For tireless commitment to AIAA technical activities, particularly the Information Systems Group, including service as Deputy Director, TC Chair, Conference Technical Chair, and IC Member.



Vicki S. Johnson
Spirit AeroSystems (retired)
For continuous, consistent, and effective contributions to and leadership and conduct of Wichita Section activities, and support of national committees, over many years.

James A. Keenan
U.S. Army Aviation & Missile Research, Development, and Engineering Center (AMRDEC)
For impactful leadership contributions to AIAA through the Thermophysicsand Applied Aerodynamics Technical Committees, Aerospace Sciences Group, Board of Directors, and Council of Directors.

Ronald J. Kohl
R J Kohl & Assoc.
For sustained service in the pursuit of technical collaborations and improved communications between numerous technical committees, between different TAD groups, and between multiple AIAA divisions.

Frank K. Lu
University of Texas at Arlington
For sustained and diverse leadership in student branch, local section, technical committee, and editorial and publications activities.

David W. Levy
Sierra Nevada Corporation
For sustained service as AIAA Wichita Section and Aircraft Design Technical Committee Chair, Design/Build/Fly Competition Contest Administrator, and Drag Prediction Workshop Organizing Committee.

Dimitri N. Mavris
Georgia Institute of Technology
For 40 years of continuous meritorious service to AIAA in technical, honors and awards, publications, and international activities.

Andrew J. Neely
UNSW Canberra at the Australian Defence Force Academy
For the sustained and trusted management of activities advancing AIAA values and interests at the section, regional, and international levels.

Krishnaswamy Ravindra
Saint Louis University
For significant contributions in aerospace engineering education and dedicated service to the AIAA Committee on Higher Education.

Joseph A. Schetz
Virginia Polytechnic Institute and State University
For sustained and outstanding service to the Institute's technical committees and publications and as Editor-in-Chief of the AIAA Education Series.

Elana M. Slagle
Starfish Education
In appreciation of her leadership in STEM advancement and continued commitment to the attributes of AIAA in the Pacific Northwest Section.

Mitchell L. Walker, II
Georgia Institute of Technology
In recognition of long-term sustained service and technical leadership of AIAA.

For more information on the Sustained Service Award, please visit **aiaa.org/awards.**

Young Professionals, Students, and Educator Conference Held Virtually in October

The AIAA Region I Young Professionals, Students, and Educator (YPSE) Conference was held virtually for the first time by the AIAA Mid-Atlantic Section on 15–16 October 2020. More than 130 young professionals (under age 35), educators, graduate, undergraduate, and high school students were in attendance. Presenters called in from across the United States and the world to give over 30 technical presentations on aerospace-related topics, including space exploration, robotics, aerodynamics, and navigation. The event was an opportunity for young professionals and students to learn from each other about a large breadth of topics in the aerospace community, gaining knowledge in areas they may not have yet been exposed to. YPSE 2020 featured a keynote address from former NASA astronaut and current Deputy Director of Engineering in the Office of the Secretary of Defense for the Undersecretary of Research and Engineering, Dr. Sandra Magnus. She discussed her distinguished career and answered questions regarding her time as an astronaut, advice for professional development and leadership development, and the aerospace profession as a whole. The conference also featured talks from AIAA Executive Director Dan Dumbacher, AIAA President Basil Hassan, and AIAA Region 1 Director Steve Bauer. The AIAA Mid-Atlantic Section will be hosting the 2021 YPSE Conference on 15 October 2021, at the Kossiakoff Center at the Johns Hopkins University Applied Physics Laboratory in Laurel, MD.

Please email **aiaa.midatlantic@gmail.com** for more details.

Check **https://engage.aiaa.org/midatlantic** for upcoming events.

MAKING AN IMPACT

Aerospace Career Pathways: AIAA Student Webinar Series

In spring 2020, AIAA launched a free webinar series called "Aerospace Career Pathways" to introduce students to a variety of career opportunities in the aerospace industry with the goal of inspiring the future workforce.

We featured seven different professionals who represent four different tracks in the aerospace industry: public service, academia, professional engineering, and entrepreneurship. Over 200 students have tuned in to learn how these individuals developed their professional skills, overcame career challenges, and gained insights that will help students during their student-to-professional transition.

While the last planned webinar in the series was released in December, all the webinars are available online and can found on the AIAA website. www.aiaa.org/events-learning/aiaa-webinars.

Help us to continue inspiring the future workforce with a gift to the AIAA Foundation. Donate today: **www.aiaa.org/foundation.**

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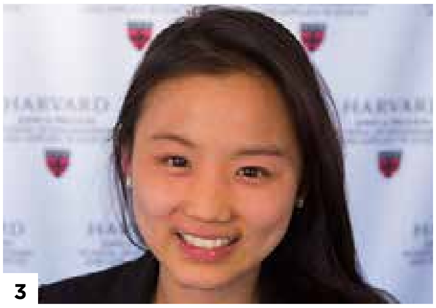

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1 Col. Brian Stahl, U.S. Air Force and Senior Air Force Advisor, Office of Undersecretary of Defense for Policy, Strategy, and Force Development, discussed career pathways for the military and public service.

2 Ingo Jahn, deputy director for the Centre for Hypersonics at the University of Queensland, explained career pathways to research, academia, publishing, and teaching.

3 Allison Tsay, a radio frequency engineer at Lockheed Martin Skunk Works, discussed professional engineering.

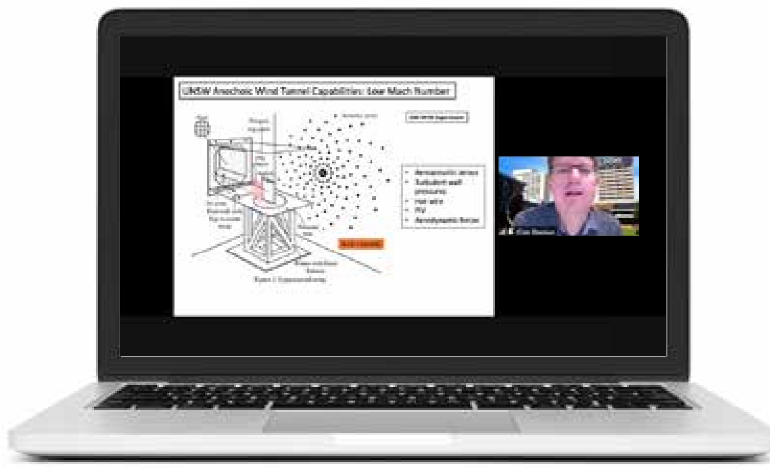
4 Victoria Chibuogu Nneji, lead engineer and innovation strategist at Edge Case Research, highlighted career pathways to entrepreneurship and business leadership.

5 Dani Soban, a senior lecturer (associate professor) in Aerospace Engineering at Queen's University Belfast in Northern Ireland, UK, explained aerospace career pathways in academia, research, teaching, and publishing.

6 Sarah Shull, NASA's Strategic Architecture and Formulation Lead for Human Missions to the Moon and Mars, discussed aerospace career pathways to government.

7 Paul Dees, Technical Fellow, Airplane Configuration & Integration at Boeing Commercial Airplanes, discussed his experiences working as a design engineer and project manager in the aircraft industry.

AIAA Sydney Section Student Conference/Region VII Student Conference Held in November



From 25 to 26 November, the AIAA Sydney Section Student Conference, held virtually and hosted by the AIAA University of New South Wales (NSW, Australia) Student Branch and the AIAA Sydney Section, took place online and featured 27 presentations from student members from eight countries. Students presented in three categories, with two categories making their debuts in the Region VII Student Conference for the first time in several years: Undergraduate, Master by Research, and Master by Coursework. Their presentations were evaluated by industry peers with many years of experience in the aerospace sector.

Judges collated their results and announced the winners of the presentation prizes, sponsored by the AIAA Sydney Section. The winners of the Undergraduate Category presentations were: 1st place – Miguel Vila of the University of New South Wales Canberra (Australia), who presented "Digital Image and Pressure Analysis of Supersonic Aerospike Instability Frequency"; 2nd place – Marco Alberto of the University of New South Wales, Sydney (Australia), who presented "Aeroacoustic Impact of Propeller Tip Geometry on Low Reynolds Number UAV Propellers"; and 3rd place – Jarrod Moonen of the Royal Melbourne Institute of Technology (Australia), who presented "Powerplant Hybridisation of a High Altitude Mountain Rescue Helicopter." The winners of the Master by Research Category were: 1st place – 2nd Lt. Francesco Riboli of Università degli Studi di Napoli Federico II (Italy), who presented "Store Separation Predictions for Weapon Integration on a Fighter-Type Aircraft"; 2nd place – Chung-Hao Ma of the University of New South Wales, Sydney (Australia), who presented "Aeroacoustics and aerodynamics of flow over a forward-backward facing step"; and 3rd place – Genya Naka of the University of Tokyo (Japan), who presented "Numerical Model of Radiative and Convective Heat Flux for Fuel Regression Rate of Wax-based Hybrid Rocket." The winners of the Master by Coursework Category were: 1st place – Yusuf Asalani of the Institut Teknologi Bandung (Indonesia), who presented "RLS-based Indirect Adaptive Model Predictive Control for Aircraft Application as MIMO Systems"; and 2nd place – Adam Arif, of the Insitut Teknologi Bandung (Indonesia), who presented "Failure Identification and Fault Tolerant Control of Passenger Aircraft."

Students also submitted their papers for technical evaluation to the Region VII Student Paper Competition, which ran concurrently with the AIAA Sydney Section Student Conference. Technical papers were evaluated and scored by industry peers all over the world. Papers were scored in two categories, Undergraduate and Master by Research. The winning Undergraduate Category papers were: 1st place – Mudit Agrawal of the University of New South Wales, Sydney with "Effect of a leading-edge fillet on wall pressure fluctuations associated with flow past an appendage-body junction"; 2nd place – Miguel Vila of the University of New South Wales Canberra, with "Digital Image and Pressure Analysis of Supersonic Aerospike Instability Frequency"; and 3rd place – Marco Alberto of the University of New South Wales Sydney, with "Aeroacoustic Impact of Propeller Tip Geometry on Low Reynolds Number UAV Propellers." The winning Master by Research Category papers were: 1st place – Genya Naka of the University of Tokyo (Japan), who presented "Numerical Model of Radiative and Convective Heat Flux for Fuel Regression Rate of Wax-based Hybrid Rocket"; 1st place – 2nd Lt. Francesco Riboli of Università degli Studi di Napoli Federico II (Italy), who presented "Store Separation Predictions for Weapon Integration on a Fighter-Type Aircraft"; and 3rd place – Chung-Hao Ma of the University of New South Wales, Sydney (Australia), who presented "Aeroacoustics and aerodynamics of flow over a forward-backward facing step." The first-place winners of the technical papers competition are invited to compete in the 2021 AIAA International Student Conference, which will take place virtually at the 2021 AIAA SciTech Forum.

AIAA would like to thank Lockheed Martin and the AIAA Sydney Section for its support of this program and would like to recognize the AIAA University of New South Wales Student Branch planning committee and its advisors, Drs. Sonya Brown and Danielle Moreau, for hosting the conference.

Dr. Tom I-P. Shih Appointed as New Editor-In-Chief of the *AIAA Journal*

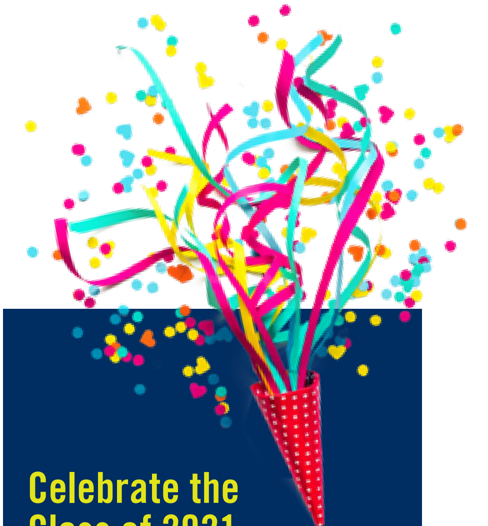
In January 2021, **Tom Shih**, Professor of Aeronautics and Astronautics at Purdue University, will assume responsibilities as the new editor-in-chief of the *AIAA Journal (AIAAJ)*. Shih succeeds Prof. Alexander Smits of Princeton University, who has served as editor-in-chief of *AIAAJ* since 2015. He was selected from a competitive pool of applicants following a rigorous search supported by the Publications Committee.

Shih holds M.S.E and Ph.D. degrees in Mechanical Engineering from the University of Michigan and a B.S.E in Mechanical Engineering from National Cheng Kung University, Tainan, Taiwan. He recently stepped down as head of the School of Aeronautics and Astronautics, serving from 2009 to 2019. Before coming to Purdue, he was chair of the Department of Aerospace Engineering at Iowa State University, from 2003 to 2009. His primary professional interests include computational fluid dynamics, gas-turbine aerodynamics and heat transfer, and thermal management of aerospace systems.

An AIAA Fellow, Shih has spent his entire career in aerospace engineering and has provided wide-ranging service to the Institute. Past AIAA awards and recognition include a service citation for contributions to the *Journal of Propulsion and Power (JPP)* in 2007, a Sustained Service Award and a Distinguished Service Award from the Terrestrial Energy Systems Technical Committee in 2010, the Energy Systems Award in 2015, and the Thermophysics Award in 2020.

Motivating Shih's interest in seeking the editor-in-chief position is the opportunity to further contribute to the profession in a meaningful way. He is well respected for his administrative skills and also for his scholarship and leadership as an educator seeking to support and inspire students to explore new research areas and disciplines. From a publishing perspective, Shih has gained significant experience as an associate editor and editorial advisory board member to a wide range of technical journals, including service to *JPP*. He can claim authorship on over 200 papers published in journals and conference proceedings.

The *AIAA Journal* was established by AIAA in 1963, following the merger of the Institute of the Aerospace Sciences and the American Rocket Society, and grew out of these predecessor societies' journals, the *Journal of the Aerospace Sciences* and *ARS Journal*, respectively. Tom Shih will become the eighth editor-in-chief of the journal.



Celebrate the Class of 2021 AIAA Associate Fellows!

THURSDAY, 21 JANUARY 2021, 1600 HRS ET

Please join us to celebrate the induction the Class of 2021 AIAA Associate Fellows. This is a free virtual event.

For viewing, please register and watch at **https://live.remo.co/e/2021-aiaa-associate-fellows-indu** (Chrome and Firefox browser only).

For more information about the Class of 2021, please visit **aiaa.org/Associate Fellows2021.**

Obituaries

AIAA Fellow Weiss Died in March

Stanley Weiss, who spent 50 years in industry, government, and academia exploring the possibilities of engineering, died on 6 March at the age of 94.

Weiss graduated from Rensselaer Polytechnic Institute with B.S (1945) and M.S. (1947) degrees in aeronautical engineering. He received a Ph.D. in theoretical and applied mechanics from the University of Illinois at Urbana (1949) and is a graduate of Harvard University's Advanced Management Program (1969). His military service was with the U.S. Navy.

Weiss spent his early career in the Midwest where he developed and analyzed aircraft design at Goodyear Aircraft Corporation and the Aircraft Products Division at Kawneer Company. He moved to California in 1957 and began his long association with Lockheed Missiles and Space Company, where he started as product manager for the Polaris Missile project. He held various positions over the years including assistant program manager and then development program manager for satellite reconnaissance programs; assistant general manager for special programs; and vice president, engineering and development.

From 1978 to 1983, Weiss served in the government, first as Deputy Assistant Secretary for Utility and Industrial Applications in the Department of Energy. He later worked at NASA as Associate Administrator for Space Transportation Operations and then as Chief Engineer, where he oversaw Spacelab development and Space Shuttle operational preparation. He received the NASA Distinguished Service Medal in 1983.

Weiss returned to Lockheed in 1987 as vice president of engineering and general manager of research and development, positions he held until his retirement in 1990.

Whether he was working on satellite programs at Lockheed Missiles and Space Company or analyzing systems at NASA in preparation for the first Space Shuttle launch, his curiosity led him in search of innovative solutions to complex problems. After retiring from Lockheed, Weiss began a 20-year academic career dedicated to helping develop the next generation of engineers and forging connections between universities and industry. At MIT, he was Jerome C. Hunsaker Visiting Professor in Aeronautical Engineering and co-principal investigator for the Lean Aerospace program. He later became a consulting professor at Stanford University in the Aeronautics and Astronautics department. During this time, he wrote *Product and Systems Development: A Value Approach* (Wiley, 2013).

Weiss participated in a variety of government panels and advisory committees. He was a Fellow of AIAA and the International Council on Systems Engineering (INCOSE).

AIAA Senior Member Sharples Died in November

Robert E. Sharples died on 22 November 2020. He was 83 years old.

Sharples graduated from Cooper Union, New York, with a B.S. in Chemical Engineering, the University of California, Berkeley, with an M.A. in Mathematics, and the University of California, Los Angeles, Executive Management Training program.

Sharples had a long career in aerospace as an engineering manager and proposal manager. He managed numerous very large proposals for Northrop Grumman/TRW, including James Webb, National Polar-Orbiting Environmental Satellite System (NPOESS), and Jupiter Icy-moons Orbiter (JIMO).

AIAA Honorary Fellow Teets Died in November

Peter B. Teets, former undersecretary and Acting Secretary of the Air Force, head of the National Reconnaissance Office, and president and chief operating officer of Lockheed Martin, died 29 November 2020.

Teets attended the University of Colorado at Boulder and the Massachusetts Institute of Technology, earning degrees in applied mathematics and business administration, respectively. He worked for the Martin Company as an engineer, working in different roles as the company expanded to become Martin Marietta Corporation. He was elected president of its Space Group in 1993, and soon after the company's 1995 merger with Lockheed Martin, became president and COO of the new Lockheed Martin Corp.

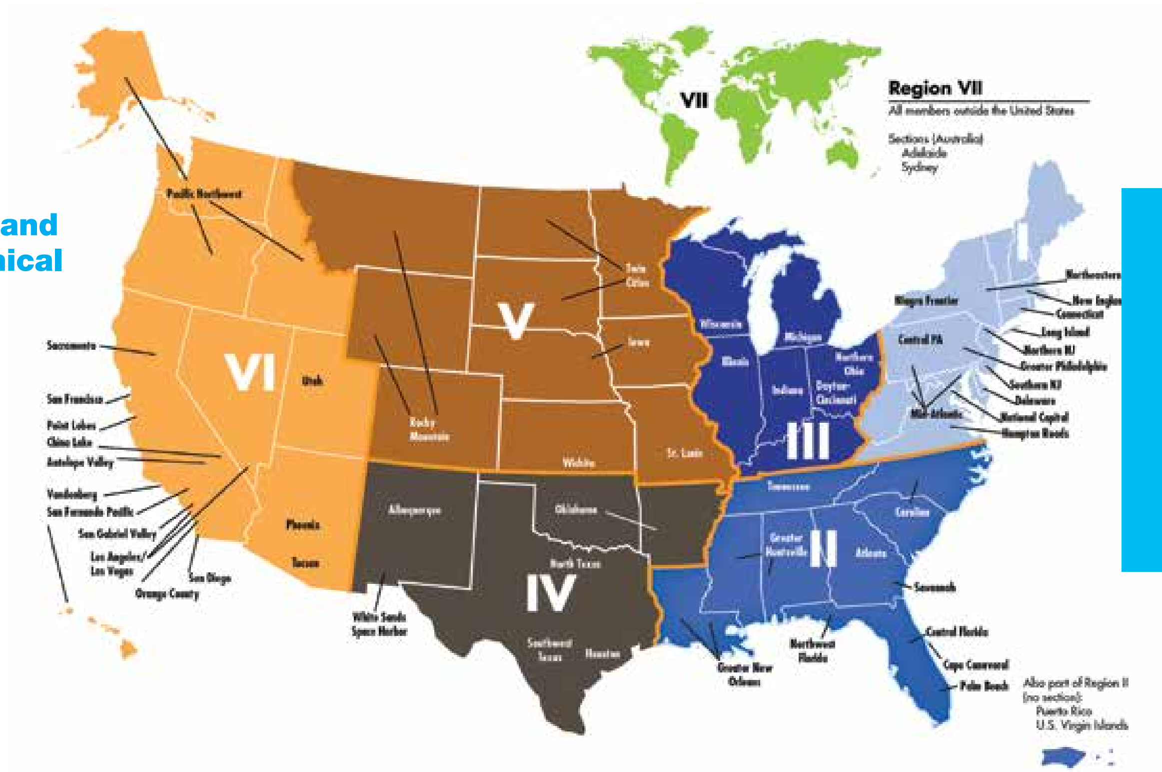
In 2001, Teets retired from Lockheed Martin and undertook the jobs of undersecretary of the Air Force and head of the National Reconnaissance Office, which then was a dual position that reported to the Secretary of the Air Force, the Secretary of Defense and head of national intelligence. He served briefly as Acting Secretary of the Air Force. Teets resigned from the undersecretary/NRO job in March 1995.

In retirement, Teets served on the boards of the Aerospace Corporation, Draper Laboratories, and Challenger Center of Colorado. He was recognized with many awards including AIAA's highest honor for notable achievements in the field of astronautics, the Goddard Astronautics Award in 2010, for his four decades of contributions to manned and unmanned access to space and significant contributions to the world's aerospace community. He also received the Wernher von Braun Space Flight Trophy, the Robert Goddard Memorial Trophy, and the Gen. James V. Hartinger Award for contributions to military space.

AIAA Student Branches, 2020–2021

AIAA has over 20 student branches around the world. Each branch has a chair elected each year, and a FA: who serves long term to support that branch's activities. Like the professionals, the student branches invite speakers, take field trips, promote career development, and participate in projects that introduce students to membership with AIAA and their professional futures. The branches, and their officers in particular, organize branch activities in addition to their full-time schoolwork, and their advisors clearly care deeply about their students' futures. Please join us in acknowledging the time and effort that all of them take to make their programs successful.

AIAA Sections and Geographical Regions



Map for posit
only. Updated
map will be
added on
Thursday

FA = Faculty Advisor
SBC: Student Branch Chair

REGION I

American Public University System
FA: Marvine Hamner
SBC: Catherine Taylor

Boston University
(New England)
FA: Sheryl Grace
SBC: Kathryn Moslener

Brown University
(New England)
FA: TBD
SBC: TBD

Carleton University
(Niagara Frontier)
FA: Steve Ulrich
SBC: Carmen Huang

Carnegie Mellon University
(Mid-Atlantic)
FA: TBD
SBC: TBD

Catholic University of America
(National Capital)
FA: Diego Turo
SBC: Virginia Boras

City College of New York
(Long Island)
FA: Prathap Ramamurthy
SBC: Mazen Alhirsh

City University of New York
(Long Island)
FA: TBD
SBC: TBD

Clarkson University
(Northeastern New York)
FA: Kenneth Visser
SBC: Colin Branigan

Columbia University
(Long Island)
FA: Robert Stark
SBC: Nathan Coulibaly

Concordia University
(Niagara Frontier)
FA: Hoi Dick Ng
SBC: TBD

Cornell University
(Niagara Frontier)
FA: Dmitry Savransky
SBC: Christopher Chan

Dartmouth College
(New England)
FA: TBD
SBC: TBD

Drexel University
(Greater Philadelphia)
FA: Ajmal Yousuff
SBC: Will Culbertson

École de Technologie Supérieure
(Niagara Frontier)
FA: Ruxandra Botez
SBC: Mathieu Lavoie

École Polytechnique de Montreal
(Niagara Frontier)
FA: TBD
SBC: TBD

George Washington University
(National Capital)
FA: Peng Wei
SBC: Joshua Groover

Hofstra University
(Long Island)
FA: John Vaccaro
SBC: TBD

Howard University
(National Capital)
FA: Nadir Yilmaz
SBC: Paa Sey

Johns Hopkins University
(Mid-Atlantic)
FA: TBD
SBC: TBD

Lehigh University
(Greater Philadelphia)
FA: Terry Hart
SBC: Michael DeMasi

Manhattan College
(Long Island)
FA: John Leylegian
SBC: Amber Perez

Massachusetts Institute of Technology
(New England)
FA: David Darmofal
SBC: Shannon Cassady

McGill University
(Niagara Frontier)
FA: TBD
SBC: TBD

National Institute of Aerospace
(Hampton Roads)
FA: TBD
SBC: TBD

New Jersey Institute of Technology
(Northern New Jersey)
FA: TBD
SBC: TBD

New York Institute of Technology
(Long Island)
FA: James Scire
SBC: TBD

Northeastern University
(New England)
FA: Andrew Gouldstone
SBC: Cameron Bracco

Old Dominion University
(Hampton Roads)
FA: Colin Britcher
SBC: Forrest Miller

Pennsylvania State University
(Central Pennsylvania)
FA: Robert Melton
SBC: Ryan James

Polytechnic Institute of Brooklyn
(Long Island)
FA: TBD
SBC: TBD

Princeton University
(Northern New Jersey)
FA: Michael Mueller
SBC: TBD

Rensselaer Polytechnic Institute
(Northeastern New York)
FA: Farhan Gandhi
SBC: Richard Healy

Rochester Institute of Technology
(Niagara Frontier)
FA: Agamemnon Crassidis
SBC: Blake Olson

Rowan University
(Southern New Jersey)
FA: John Schmalzel
SBC: Nicholas Gushue

Royal Military College of Canada
(Niagara Frontier)
FA: Ruben Perez
SBC: TBD

Rutgers University
(Northern New Jersey)
SBC: Steven Calalpa
FA: Francisco Diez

Ryerson University
(Niagara Frontier)
FA: Seyed Hashemi
SBC: TBD

Southern New Hampshire University
(New England)
FA: Xinyun Guo
SBC: Rasheed Blake

Stevens Institute of Technology
(Northern New Jersey)
FA: Siva Thangam
SBC: Amir Choudhury

Stony Brook University
(Long Island)
FA: Sotirios Mamalis
SBC: Le Si Qu

SUNY/Buffalo
(Niagara Frontier)
FA: Paul Schifferle
SBC: Michael Berger

Syracuse University
(Northeastern New York)
FA: John Dannenhoffer
SBC: Paul Mokotoff

United States Military Academy-West Point
(Long Island)
FA: Jeremy Paquin
SBC: Brandon Cea

United States Naval Academy
(Mid-Atlantic)
FA: Jeffery King
SBC: Alec Engl

University of Connecticut
(Connecticut)
FA: Chih-Jen Sung
SBC: Stephen Price

University of Delaware
(Delaware)
FA: TBD
SBC: TBD

University of Maine
(New England)
FA: Alexander Friess
SBC: Jack O'Kelly

University of Maryland,
Baltimore County
(Mid-Atlantic)
FA: Charles Eggleton
SBC: Caroline Vantiem

University of Maryland-College Park
(National Capital)
FA: Norman Wereley
SBC: Rachel Cueva

University of Massachusetts Lowell
(New England)
FA: Marianna Maiaru
SBC: TBD

University of Pittsburgh
(Mid-Atlantic)
FA: Peyman Givi
SBC: TBD

University of Toronto
(Niagara Frontier)
FA: Kamran Behdinan
SBC: TBD

University of Vermont
(New England)
FA: William Louisos
SBC: Anthony Julian

University of Virginia
(National Capital)
FA: Christopher Goyne
SBC: Rikia Freeman

Vaughn College of Aeronautics and Technology
(Long Island)
FA: Amir Elzawawy
SBC: Utsav Shah

Villanova University
(Greater Philadelphia)
FA: Sergey Nersesov
SBC: Nick Florio

Virginia Polytechnic Institute and State University
(Hampton Roads)
FA: Mayuresh Patil
SBC: Todd Stefan

Wentworth Institute of Technology
(New England)
FA: Haifa El-Sadi
SBC: Kylee Julia

West Virginia University
(Mid-Atlantic)
FA: Christopher Griffin
SBC: Zachary Halterman

Worcester Polytechnic Institute
(New England)
FA: John Blandino
SBC: Krystina Waters

Yale University
(Connecticut)
FA: Mitchell Smooke
SBC: Rowan Palmer

REGION II

Alabama A&M University
(Greater Huntsville)
FA: TBD
SBC: TBD

Athens State University
(Greater Huntsville)
FA: J Wayne McCain
FA: Michelle Allen

Auburn University
(Greater Huntsville)
FA: Rob Kulick
FA: Norm Speakman
SBC: Olivia Green

Duke University
(Carolina)
FA: Kenneth Hall
SBC: Miles Burnette

East Carolina University
(Carolina)
FA: Tarek Abdel-Salam
SBC: Jacob Rose

Embry-Riddle Aero Univ-Daytona Beach/FL
(Cape Canaveral)
FA: Habib Eslami
SBC: Andrew Beres

Florida A&M University
(Northwest Florida)
FA: Chiang Shih
SBC: TBD

Florida Atlantic University
(Palm Beach)
FA: Stewart Glegg
SBC: Diego Salvatierra

Florida Institute of Technology
(Cape Canaveral)
FA: David Fleming
SBC: Sean Dungan

Florida International University
(Palm Beach)
FA: George Dulikravich
SBC: Matthew Barreto

Florida State University
(Northwest Florida)
FA: TBD
SBC: Austin Robertson

Georgia Institute of Technology
(Atlanta)
FA: Dimitri Mavris
SBC: Andrew Morell

Kennesaw State University
(Atlanta)
FA: Adeel Khalid
SBC: Cindy Vo

Louisiana State University
(Greater New Orleans)
FA: Keith Gonthier
SBC: Jacqueline Cloutier

Mississippi State University
(Greater Huntsville)
FA: Robert Wolz
SBC: Ryan Cook

North Carolina A&T State University
(Carolina)
FA: Michael Atkinson
SBC: Donovan McGruder

North Carolina State University
(Carolina)
FA: Jack Edwards
SBC: Carissa Hardy

Polytechnic University of Puerto Rico
(Palm Beach)
FA: Jose Pertierra
SBC: Yan Casanova

Tennessee Tech University
(Tennessee)
FA: TBD
SBC: TBD

Tuskegee University
(Greater Huntsville)
FA: Mohammad Khan
SBC: Stefon Harris

University of Alabama at Birmingham
(Greater Huntsville)
FA: Roy Koomullil
SBC: Jordan Fuse

University of Alabama-Huntsville
(Greater Huntsville)
FA: D Brian Landrum
SBC: Jacob Clark

University of Alabama-Tuscaloosa
(Greater Huntsville)
FA: Weihua Su
SBC: Abby Feeder

University of Central Florida
(Central Florida)
FA: Seetha Raghavan
SBC: Emma Turner

University of Florida-Gainesville
(Central Florida)
FA: Richard Lind
SBC: Jose Aguilar

University of Memphis
(Tennessee)
FA: Jeff Marchetta
SBC: William Bowen

University of Miami-Coral Gables
(Palm Beach)
FA: Ryan Karkkainen
SBC: TBD

University of Mississippi
(Greater Huntsville)
FA: TBD
SBC: TBD

University of North Carolina at Charlotte
(Carolina)
FA: Jerry Dahlberg
SBC: Spencer Owen

University of Puerto Rico
(Palm Beach)
FA: Guillermo Araya
SBC: Harrison Rivera Colon

University of South Alabama
(Greater Huntsville)
FA: Carlos Montalvo
SBC: Jossellyn Vieyra-Sanchez

University of South Carolina
(Carolina)
FA: Michael Van Tooren
SBC: Floris Van Zanten

University of South Florida
(Central Florida)
FA: TBD
SBC: TBD

University of Tennessee Knoxville
(Tennessee)
FA: James Corder
SBC: Benjamin Ingling

University of Tennessee Space Institute
(Tennessee)
FA: Trevor Moeller
SBC: Lauren Lester

University of Tennessee-Chattanooga
(Tennessee)
FA: Kidambi Sreenivas
SBC: Morgan Young

University of West Florida
(Northwest Florida)
FA: Carolyn Mattick
SBC: William Preston

Vanderbilt University
(Tennessee)
FA: Amrutur Anilkumar
SBC: Cameron Schepner

REGION III

Air Force Institute of Technology
(Dayton/Cincinnati)
FA: Marc Polanka
SBC: Matthew Fuqua

Case Western Reserve University
(Northern Ohio)
FA: Paul Barnhart
SBC: Genevieve Timmermann

Cleveland State University
(Northern Ohio)
FA: Nicole Strah
SBC: Zach Allen

Illinois Institute of Technology
(Illinois)
FA: Boris Pervan
SBC: Zoey Krevitz

Indiana University-Purdue Univ Indianapolis
(Indiana)
FA: Hamid Dalir
SBC: TBD

Kettering University (Michigan)
FA: TBD
SBC: TBD

Lawrence Technological Unversity
(Michigan)
FA: Andrew Gerhart
SBC: Rose Gebara

Michigan State University (Michigan)
FA: Patton Allison
SBC: Douglas Heine

Miami University (Dayton/Cincinnati)
FA: James Van Kuren
SBC: Nick Toll

Milwaukee School of Engineering
(Wisconsin)
FA: William Farrow
SBC: Nicholas Hahn

Ohio Northern University
(Dayton/Cincinnati)
FA: Jed Marquart
SBC: Anthony Bothe

Ohio State University (Dayton/Cincinnati)
FA: Ali Jhemi
SBC: Tony Kuenzli

Ohio University (Dayton/Cincinnati)
FA: Dennis Irwin
SBC: Elijah Couchman

Purdue University (Indiana)
FA: Li Qiao
SBC: Zach Marshall

Rose Hulman Institute of Technology (Indiana)
FA: Calvin Lui
SBC: Taylor Lueking

Trine University (Indiana)
FA: James Canino
SBC: Ismar Chew

University of Akron (Northern Ohio)
FA: Alexander Povitsky
SBC: Matthew Ripple

University of Cincinnati (Dayton/Cincinnati)
FA: Bryan Brown
SBC: Matthew Ha

University of Dayton (Dayton/Cincinnati)
FA: Sidaard Gunasekaran
SBC: Scott Chriss

University of Illinois at Chicago (Illinois)
FA: Kenneth Brezinsky
SBC: Christopher Dantis

University of Illinois at Urbana-Champaign (Illinois)
FA: Laura Villafañe Roca
SBC: Ari Jain

University of Kentucky-Lexington (Dayton/Cincinnati)
FA: Alexandre Martin
SBC: Michael McKinney

University of Kentucky-Paducah (Dayton/Cincinnati)
FA: Sergiy Markutsya
SBC: Lexi Parks

University of Michigan at Ann Arbor (Michigan)
FA: Benjamin Jorns
SBC: James Stieber

University of Notre Dame (Indiana)
FA: Thomas Juliano
SBC: Michael Rogers

University of Wisconsin-Madison (Wisconsin)
FA: Matthew Allen
SBC: Sam Jaeger

University of Wisconsin-Milwaukee (Wisconsin)
FA: Ryoichi Amano
SBC: Abdel Rahman Salem

Western Michigan University (Michigan)
FA: Peter Gustafson
SBC: Ethan Reid

Wright State University (Dayton/Cincinnati)
FA: Mitchell Wolff
SBC: Hunter Gilliland

Youngstown State University (Northern Ohio)
FA: Kevin Disotell
SBC: TBD

REGION IV

Lamar University (Houston)
FA: Kendrick Aung
SBC: Mason Munoz

New Mexico Institute of Mining and Technology (Albuquerque)
FA: Mostafa Hassanalian
SBC: Savannah Bradley

New Mexico State University (White Sands Space Harbor)
FA: Andreas Gross
SBC: Ian Ruacho

Oklahoma State University (Oklahoma)
FA: Andrew Arena
SBC: Alex Greenfeather

Rice University (Houston)
FA: Andrew Meade
SBC: Wyatt Crider

Texas A&M University (Houston)
FA: Gregory Chamitoff
SBC: Matthew Elmer

Universidad Autonoma de Baja California
FA: Juan Antonio Paz
SBC: Christian Sanchez

Universidad Autonoma de Chihuahua
FA: Carlos Sanchez
SBC: Fernando Fernandez

University of Arkansas-Fayetteville (Oklahoma)
FA: Po-Hao Huang
SBC: Andrew Overton

University of Houston (Houston)
FA: Edgar Bering
SBC: Kelly Graham

University of New Mexico (Albuquerque)
FA: Svetlana Poroseva
SBC: Jeremy Holder

University of Oklahoma (Oklahoma)
FA: Thomas Hays
SBC: Alexandria Caudill

University of Texas at Dallas (North Texas)
FA: Arif Malik
SBC: Rohit Gattamaraju

University of Texas at San Antonio (Southwest Texas)
FA: Christopher Combs
SBC: Austin Rendon

University of Texas El Paso (White Sands Space Harbor)
FA: Jack Chessa
SBC: Rene Aguilar

University of Texas-Arlington (North Texas)
FA: Zhen-Xue Han
SBC: Michael Ibanez

University of Texas-Austin (Southwest Texas)
FA: Renato Zanetti
SBC: TBD

REGION V

Colorado School of Mines (Rocky Mountain)
FA: Angel Abbud-Madrid
SBC: Claire Thomas

Colorado State University (Rocky Mountain)
FA: Xinfeng Gao
SBC: Brennan O'Connor

Iowa State University (Iowa)
FA: Anupam Sharma
SBC: Andrew Townsend

Kansas State University (Wichita)
FA: TBD
SBC: TBD

Metropolitan State University of Denver (Rocky Mountain)
FA: Randall Owen
SBC: Jonathan Swavely

Missouri University of Science and Technology (St. Louis)
FA: Kakkattukuzhy Isaac
SBC: Rory Margherio

North Dakota State University (Twin Cities)
FA: Yildirim Suzen
SBC: TBD

Saint Louis University (St. Louis)
FA: Michael Swartwout
SBC: Samantha Carlowicz

United States Air Force Academy (Rocky Mountain)
FA: Barrett McCann
SBC: TBD

University of Colorado-Boulder (Rocky Mountain)
FA: Donna Gerren
SBC: James Guthrie

University of Colorado-Colorado Springs (Rocky Mountain)
FA: Lynnane George
SBC: Natalie Dilts

University of Iowa (Iowa)
FA: Kamran Samani
SBC: AJ Schmitt

University of Kansas (Wichita)
FA: Ronald Barrett-Gonzalez
SBC: Ethan Wissmann

University of Minnesota (Twin Cities)
FA: Yohannes Ketema
SBC: Campbell Dunham

University of Missouri-Columbia (St. Louis)
FA: Craig Kluever
SBC: Kendall Feist

University of Missouri-Kansas City (Wichita)
FA: Travis Fields
SBC: Shawn Herrington

University of North Dakota (Twin Cities)
FA: TBD
SBC: TBD

University of Wyoming (Rocky Mountain)
FA: TBD
SBC: TBD

Washington University in St Louis (St. Louis)
FA: Swami Karunamoorthy
SBC: Jonathan Richter

Wichita State University (Wichita)
FA: Linda Kliment
SBC: Colton Wagner

REGION VI

Arizona State University (Phoenix)
FA: Timothy Takahashi
SBC: Ryley Miller

Arizona State University Polytechnic Campus (Phoenix)
FA: TBD
SBC: TBD

Boise State University (Pacific Northwest)
FA: TBD
SBC: TBD

Brigham Young University (Utah)
FA: Andrew Ning
SBC: Jon Rice

California Institute of Technology (San Gabriel Valley)
FA: Soon-Jo Chung
SBC: Luis Pabon Madrid

California Polytechnic State University-Pomona
(San Gabriel Valley)
FA: Subodh Bhandari
SBC: Nathan Watje

California Polytechnic State University-San Luis Obispo
(Vandenberg)
SBC: Aaron Drake
SBC: Nicole Bartal

California State University, Fresno (Antelope Valley)
FA: Deify Law
SBC: Kyle Sweeney

California State University-Fullerton (Orange County)
FA: Salvador Mayoral
SBC: TBD

California State University-Long Beach (Los Angeles-Las Vegas)
FA: Eun Jung Chae
SBC: Ian Clavio

California State University-Northridge (San Fernando Pacific)
FA: Peter Bishay
SBC: Luis Ferrusquilla

California State University-Sacramento (Sacramento)
FA: Ilhan Tuzcu
SBC: TBD

Embry-Riddle Aero Univ-Prescott/AZ (Phoenix)
FA: David Lanning
SBC: Elizabeth Mitchell

Northern Arizona University (Phoenix)
FA: TBD
SBC: TBD

Oregon State University (Pacific Northwest)
FA: Roberto Albertani
SBC: Adam Ragle

Portland State University (Pacific Northwest)
FA: Andrew Greenberg
SBC: Jim Foley

San Diego State University (San Diego)
FA: Allen Plotkin
SBC: Diego Chavez

San Jose State University (San Francisco)
FA: Periklis Papadopoulos
SBC: Fernando Ferreira-Velaquez

Santa Clara University (San Francisco)
FA: Christopher Kitts
SBC: Karla Raigoza

Stanford University (San Francisco)
FA: Stephen Rock
SBC: Racheal Erhard

University of Alaska-Fairbanks (Pacific Northwest)
FA: Michael Hatfield
SBC: Zachary Barnes

University of Arizona at Tucson (Tucson)
FA: Jekan Thangavelautham
SBC: Matthew Banko

University of California/Berkeley (San Francisco)
FA: George Anwar
SBC: Parker Trautwein

University of California/Davis (Sacramento)
FA: Case Van Dam
SBC: Balram Kandoria

University of California/Irvine (Orange County)
FA: Haitham Taha
SBC: Grant Tsuji

University of California/Los Angeles (Los Angeles-Las Vegas)
FA: Jeff Eldredge
SBC: Oliver Lam

University of California/Merced (Sacramento)
FA: Yang Quan Chen
SBC: Tomny Hang

University of California/San Diego (San Diego)
FA: Mark Anderson
SBC: Brenda Williamson

University of Idaho (Pacific Northwest)
FA: TBD
SBC: TBD

University of Nevada/Las Vegas (Los Angeles-Las Vegas)
FA: William Culbreth
SBC: Jet Baroudi

University of Nevada-Reno (Sacramento)
FA: Jeffrey LaCombe
SBC: Kevin Watson

University of Southern California (Los Angeles-Las Vegas)
FA: Geoffrey Spedding
SBC: Randi Arteaga

University of Utah (Utah)
FA: TBD
SBC: TBD

University of Washington at Seattle (Pacific Northwest)
FA: Behcet Acikmese
SBC: Athil George

Utah State University (Utah)
FA: Stephen Whitmore
SBC: Daniel Falslev

Washington State University (Pacific Northwest)
FA: Colin Merriman
SBC: Roman Sanelli

Weber State University (Utah)
FA: TBD
SBC: TBD

REGION VII

Beihang University
FA: Zhiqiang Wan
SBC: TBD

British University of Egypt
FA: Talat Refai
SBC: TBD

Cairo University
FA: Osama Saaid Mohammady
SBC: TBD

Chulalongkorn University
FA: Joshua Staubs
SBC: Supakorn Suttiruang

Emirates Aviation College
FA: TBD
SBC: TBD

Ghulam Ishaq Khan Institute of Engrg Sciences and Technology
FA: Khalid Rahman
SBC: TBD

Hindustan University
FA: TBD
SBC: TBD

Hong Kong University of Science & Technology/China
FA: Larry Li
SBC: Marco Clark

Indian Institute of Tech Kanpur
FA: TBD
SBC: TBD

Institute of Space Technology/Pakistan
FA: Abid Khan
FA: Shuja Rehman
SBC: Muhammad Farhan

Istanbul Technical University
FA: TBD
SBC: TBD

Khalifa University of Science Technology and Research
FA: Ashraf Al-khateeb
SBC: Nouf Al Suwaidi

Korea Advanced Institute of Science and Technology (KAIST)
FA: Jiyun Lee
SBC: You Hwankyun

Middle East Technical University
FA: TBD
SBC: TBD

MLR Institute of Technoloy
FA: TBD
SBC: TBD

Monash University
FA: Daniel Edgington-Mitchell
SBC: Sweta Balakrishna

Moscow Aviation Institute
FA: TBD
SBC: TBD

Nagoya University
FA: TBD
SBC: TBD

Nanjing University of Aeronautics and Astronautics
FA: TBD
SBC: TBD

Northwestern Polytechnical University
FA: Zhicun Yang
SBC: TBD

Queen's University Belfast
FA: TBD
SBC: TBD

Royal Melbourne Institute of Technology
FA: Cees Bil
SBC: Nick Vrazas

Technion Institute of Technology
FA: TBD
SBC: TBD

United Arab Emirates University
FA: Emad Eldeen Jamil Elnajjar
SBC: TBD

University of Adelaide/AustraliaAdelaide
FA: Rey Chin
SBC: Natalie Hayman

Universidad Pontificia Bolivariana
FA: TBD
SBC: TBD

Universidad de San Buenaventura
FA: TBD
SBC: TBD

Universita di Naples Federico II
FA: Francesco Marulo
SBC: TBD

Universita di Roma - La Sapienza
FA: Giuliano Coppotelli
SBC: Alessandro Cervelli

Universita Pontificia Bolivariana
FA: Juan Alvarado Perilla
SBC: TBD

University of Canterbury
FA: Dan Zhao
SBC: Sam Wall

University of New South Wales (Sydney)
FA: Danielle Moreau
SBC: Muhammad Arfin

University of Palermo
FA: TBD
SBC: TBD

University of Queensland
FA: TBD
SBC: TBD

Universität Stuttgart
FA: TBD
SBC: TBD

University of Sydney
(Sydney)
FA: Gareth Vio
SBC: Cole Scott-Curwood

Von Karman Institute of Fluid Dynamics
FA: TBD
SBC: TBD

AUBURN UNIVERSITY
SAMUEL GINN COLLEGE OF ENGINEERING

Multiple Open Rank Tenure-Track Faculty Positions

The Department of Aerospace Engineering at Auburn University invites applications for multiple **open rank tenure-track faculty positions (Assistant, Associate or Full Professor)**. Applications are invited in all areas related to aerospace engineering. Candidates are strongly encouraged to apply with expertise in: aerodynamics and propulsion; computational fluid dynamics; flight dynamics; and space systems and payloads. Candidates will be expected to fully contribute to the department's mission through (i) the development of a strong, nationally recognized, funded research program, (ii) teaching aerospace engineering related courses at both the undergraduate and graduate level, and (iii) professional service. Successful candidates will have a demonstrated track record of scholarship, a creative vision for research, an active interest in engineering education, and strong communication skills. For applications at the rank of Associate or Full Professor, an emphasis will be placed on the strength and caliber of the candidate's existing research program and the candidate's ability and desire to provide mentorship and leadership to a young, enthusiastic, and rapidly growing department. Candidates must have an earned Ph.D. in aerospace, mechanical engineering, or a closely related field at the time of employment.

The Department of Aerospace Engineering at Auburn University is in the midst of unprecedented growth with undergraduate enrollment increasing by over 50% in last six years to 535 students. This growth has been complemented by aggressive faculty hiring with the department now consisting of four full professors, one associate professor, eight assistant professors and two lecturers. Our current focus is on the development of world-class research programs and growth of the graduate student body from its current size of 72 students to a goal number of over 100 graduate students within the next five years. The department is part of the Samuel Ginn College of Engineering, which has a total enrollment of over 6,500 students and is home to several nationally recognized research centers, which among others would include National Center for Additive Manufacturing Excellence (NCAME), Center for Polymer, Advanced Composites (CPAC), Center for Advanced Vehicle and Extreme Environment Electronics (CAVE3), Auburn University Small Satellite Program, and Cyber Research Center. Auburn University's proximity to the aerospace, defense, and government enterprises located from Huntsville, AL down to the Florida Space Coast presents a unique opportunity for the department to emerge from this growth phase as one of the premier aerospace engineering departments in the country. Additional information about the department may be found at: www.eng.auburn.edu/aero/.

Auburn University. (www.auburn.edu/) is one of the nation's premier public land-grant institutions. In 2020, the college of engineering was ranked 29th among public universities by U.S. News and World Report. Auburn maintains high levels of research activity and high standards for teaching excellence, offering Bachelor's, Master's, Educational Specialist, and Doctor's degrees in engineering and agriculture, the professions, and the arts and sciences. Its 2020 enrollment of 30,737 students includes 24,505 undergraduates and 6,232 graduate and professional students. Organized into twelve academic colleges and schools, Auburn's 1,450 faculty members offer more than 200 educational programs. The University is nationally recognized for its commitment to academic excellence, its positive work environment, its student engagement, and its beautiful campus. Auburn (https://www.auburnalabama.org) residents enjoy a thriving community, recognized as one of the "best small towns in America," with moderate climate and easy access to major cities or to beach and mountain recreational facilities. Situated along the rapidly developing I-85 corridor between Atlanta, Georgia, and Montgomery, Alabama, the combined Auburn-Opelika-Columbus statistical area has a population of over 500,000, with excellent public school systems and regional medical centers.

Candidates should log in and submit a cover letter, CV, research vision, teaching philosophy, statement on diversity, equity and inclusion, and three references at www.auemployment.com/postings/19572. Cover letters may be addressed to: Dr. Brian Thurow, Search Committee Chair, 211 Davis Hall, Auburn University, AL 36849. To ensure full consideration, candidates are encouraged to apply before December 1, 2020 although applications will be accepted until the positions are filled. The successful candidate must meet eligibility requirements to work in the U.S. at the time the appointment begins and continue working legally for the proposed term of employment.

Auburn University is understanding of and sensitive to the family needs of faculty, including career couples. See "Guidelines for Dual Career Services" www.auburn.edu/academic/provost/policies-guidelines/#guidelines

Auburn University is an EEO/Vet/Disability Employer

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College of Science and Engineering

UNIVERSITY OF MINNESOTA

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AEM is committed to the goal of achieving a diverse faculty as a way to maximize the impact of its teaching and research mission. To learn more about UMN equity and diversity visit diversity.umn.edu.

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Required attachments: 1) cover letter, 2) detailed resume, 3) names and contact information of three references, 4) a statement of teaching interests, and, 5) a statement of research interests. The teaching and research statements should include prior or proposed contributions to diversity, equity and inclusion.

Application Deadline: Review of applications will begin on December 1, 2020; applications will be accepted until the position is filled.

The University of Minnesota is an equal opportunity educator and employer.

JAHNIVERSE

CONTINUED FROM PAGE 66

This is where big data has a role. Let's assume that the information content, for what we wish to know, in any specific source of data is zero. However, by creating a big data problem, aggregating massive quantities of disparate sources of data, we can create an opportunity for ourselves to discover something that is only measured in the mutual information of this multi-source data set. For example, I may have lots of data about solar flux activity, a separate set of data on satellite locations in multiple orbital regions, a separate set of data on hardware that some of these satellites may be equipped with, and finally a separate set of data on satellite failures or anomalies. By aggregating and curating this multisource data set, my question might be, "is there a causal relationship between space environment phenomena and satellite hardware loss, disruption, or degradation?" No single source of these data can answer this question because the answer is only contained in the mutual information content of this multisource data set. Linking these disparate data sets transforms an unknown unknown to an unknown known. Asking a relevant question of this mutual information found in the multisource data set enables me to transform this unknown known to a known known.

In order to realistically create this mutual information landscape that is exploitable, I need to perform data engineering, modeling and curation. In essence, I need to develop and maintain a digital library along with a data dictionary that describes these data, defines their meaning, orients them in their proper scales and frames of reference, and makes this semantically and even scientifically consistent to be meaningfully queried. A user should be empowered to query this aggregated data,and receive knowledge as a consequence. The goal must be successful decision intelligence, which is the ability to understand, use and manage information in such a way that leads to desired outcomes.

We don't have that capability, at least in the U.S. space community, because of a misperception. Most people confuse having lots of data to curate and manage with having a "big data" problem, which is the challenge of fusing lots of data from disparate sources.

Once a big data process is established for the space domain, satellite operators and legislators would have the knowledge required to satisfy the plethora of space safety, security and sustainability needs and demands for space activities. Unknown unknowns will be turned into unknown knowns through data aggregation and fusion, and then into known knowns. Until then, I shall continue to be a decision intelligence evangelist. ★

LOOKING BACK

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1921

1 **Jan. 21** Noted aviation pioneer Gianni Caproni launches the first aircraft to feature three sets of triplane wings, the massive Ca.60. It is also the first aircraft designed to carry 150 passengers. The Ca.60 lifts off from the surface of Lake Maggiore in Italy under the power of eight 400-horsepower Liberty engines. On the second flight, in March, the aircraft will sink into the lake. David Baker, **Flight and Flying: A Chronology**, p. 137.

2 **Jan. 27** The British R.34 airship is destroyed when it flies into a hill in Yorkshire under foggy conditions. While attempts are made to save the ship, the damage is irreparable. The R.34 made history when it crossed the Atlantic nonstop in both directions in 1919. David Baker, **Flight and Flying: A Chronology**, p. 137.

Jan. 28 Robert H. Goddard visits the Linde Air Products Co., manufacturer of liquid oxygen, to obtain a sample, marking his transition from experimenting with solid fuel to liquid fuel in rocket development. The liquid oxygen, now commonly called "lox," is to be his oxidizer, the substance in which the fuel burns. Goddard chooses gasoline as his fuel since it is cheap and readily available, and in 1926, he uses these propellants to launch the first liquid fuel rocket. Esther C. Goddard and G. Edward Pendray, eds., **The Papers of Robert H. Goddard, Vol. I**, p. 460.

1946

Jan. 10 A U.S. Army Sikorsky R-5 sets an unofficial world helicopter record by climbing to 21,000 feet from the Sikorsky plant in Stratford, Connecticut. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 52.

Jan. 16 The U.S. upper atmospheric research program, using captured V-2 rockets, is initiated. A V-2 panel of interested agencies is created and more than 60 V-2s are fired at the Army's White Sands Proving Range in New Mexico before the supply runs out. As a result of the program, the Applied Physics Laboratory of Johns Hopkins University develops a medium-altitude research rocket, the Aerobee, while the Naval Research Laboratory develops a large, high-altitude rocket called the Neptune (later renamed the Viking). E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 53.

3 **Jan. 19** Bell Aircraft test pilot Jack Woolams makes the first unpowered glide flight of the Army Air Forces-NACA Bell XS-1 rocket research airplane at Pinecastle Army Air Base in Florida. A Boeing B-29 Superfortress carries and drops the craft. Woolams, a noted racing and test pilot, reports that the new experimental aircraft has surprisingly well-coordinated controls and flies well without power. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 53.

Jan. 26 A coast-to-coast speed record is set when a Lockheed P-80 Shooting Star jet fighter is flown from Long Beach, California, to La Guardia Field, New York, in four hours, 13 minutes, at an average speed of 939 kph (584 mph). **The Aeroplane**, Feb. 1, 1946, p. 124.

1971

Jan. 1 Two galaxies are discovered, according to the Astrophysical Journal. Maffei 1 and Maffei 2, named after their discoverer, the Italian astronomer Paolo Maffei, are about 3 million light years from Earth. In 1968, Maffei had observed two strange objects on an infrared photo of a region between constellations Perseius and Cassiopeia and that had been previously obscured by interstellar dust. A team of astronomers of the University of California at Berkeley, Caltech and the Carnegie Institution confirmed the discovery with tools including the Mount Palomar and Lick Observatory telescopes, according to the report in the journal. **Astrophysical Journal**, Jan. 1, 1971.

4 **Jan. 23** Lovell Lawrence Jr. dies at age 55. He was one of the four founders and the first president of Reaction Motors Inc., or RMI, the United States' first liquid-propellant rocket engine company. James H. Wyld, well known for his development of the Wyld regeneratively cooled rocket motor, John Shesta, Hugh F. Pierce and Lawrence formed RMI in December 1941, two weeks after Pearl Harbor was bombed. All were members of the American Rocket Society, the predecessor of AIAA. Although a small company, RMI developed and built the 6000C-4 engine that powered the Bell X-1 that achieved the first supersonic flight in 1947. New York Times, Jan. 25, 1971, p. 39; Frank H. Winter, **America's First Rocket Company: Reaction Motors, Inc.**, passim.

Jan. 25-26 The Intelsat-IV F-2 communications satellite is launched by NASA for Communications Satellite Corp., on behalf of Intelsat, on an Atlas-Centaur booster from Cape Canaveral, Florida. The satellite is the first in the Intelsat-IV series and the largest commercial communications satellite launched to date, at 5.4 meters high, 2.3 meters in diameter and weighing 1,397 kilograms at launch. It has 12 responders, providing a dozen TV channels and 3,000 to 9,000 telephone circuits and is capable of multiple-access and simultaneous transmissions. **Astronautics and Astronautics, 1971**, p. 14.

5 **Jan. 26** Sen. Edward Kennedy of Massachusetts introduces a bill in the Senate to authorize the National Park Service's acquisition of the historic site at Auburn, Mass., where Robert H. Goddard (in photo) launched the world's first liquid-propellant rocket on March 16, 1926. **Astronautics and Astronautics, 1971**, p. 17.

Jan. 27 The National Religious Broadcasters association at its annual convention in Washington, D.C., beams its closing program around the world in the first international religious broadcast transmitted live by satellite, **New York Times**, Jan. 28, 1971, p. 1.

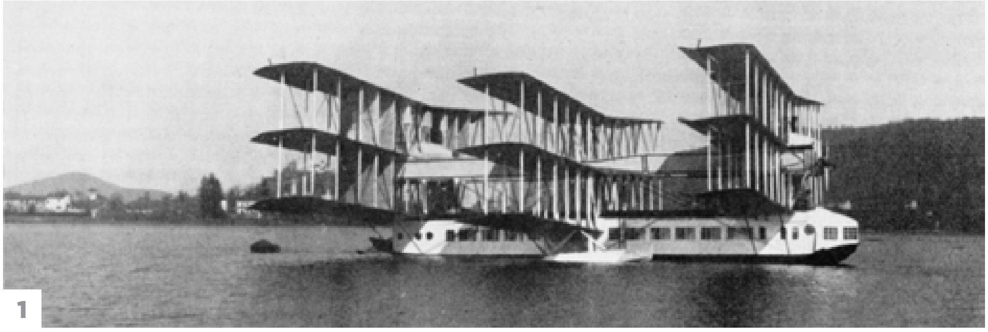
6 **Jan. 31-Feb. 9** NASA's Apollo 14 mission carrying astronauts Alan Shepard, Stuart Roosa and Edgar Mitchell is launched on a Saturn V rocket. Shepard and Mitchell land on the moon's Fra Mauro region in the lunar highlands. During two walks on the surface, they collect 42.8 kilograms of moon rocks and deploy scientific experiments. **New York Times**, Feb. 1-10, 1971.

1996

Jan. 12 Space shuttle Endeavour is launched from Kennedy Space Center in Florida. Among the six-man crew is Koichi Wakata of Japan. One of Endeavour's missions is to retrieve the Japanese Space Flying Unit from orbit. The crew will test new spacesuits that better protect astronauts from the cold during extended spacewalks. As part of the mission, the crew will operate the robotic arm to retrieve the 1,100-kilogram NASA Office of Aeronautics and Space Technology Flyer satellite. Endeavour returns to Earth on Jan. 21. NASA, **Astronautics and Aeronautics: A Chronology, 1996-2000**, p. 2.

Jan. 12 Measat-1, the first Malaysia East Asia Satellite, is orbited by an Ariane 4 rocket from the European Space Agency's site in French Guiana. Measat-1 is used by the government of Malaysia to control news broadcasts in that country. The spin-stabilized 1,500-kilogram communication satellite was built by Hughes. **Aviation Week**, Jan. 22, 1996, p. 56.

Jan. 30 NASA and the Russian Space Agency announce they have agreed to extend their shuttle and Mir collaboration until 1998. This will help the United States and Russia maintain the Mir space station, which it is hoped will lead to the completion of the International Space Station. The first node of the ISS from NASA is scheduled for launch in December 1997. NASA, **Astronautics and Aeronautics: A Chronology, 1996-2000**, p. 4.



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NASA

▶ The Apollo 14 crew, at front from left, Ed Mitchell, Stuart Roosa and Alan Shepard, look at some of the lunar rocks they brought back from the moon.

In space, finding the facts we don't know we know

BY MORIBA JAH

Back in 2002, then-Defense Secretary Donald Rumsfeld famously waxed bureaucratic at a Defense Department briefing: "As we know, there are known knowns. There are things we know we know. We also know there are known unknowns. That is to say, we know there are some things we do not know. But there are also unknown unknowns. The ones we don't know we don't know." Well, beyond a funny sound bite, Rumsfeld missed a major category: the Unknown Knowns, which in his phraseology would be "things we do not know that we know."

In order to know something, you have to measure it. So, interpret the first word in the pair as what you are aware of and the last word in the pair as what you have measured. Therefore, a known known is something you are aware of that's been measured. A known unknown is something you are aware of that has not been measured. The unknown unknown is something that can't be known by definition because you are unaware of it and you've not measured it. Again, anything that is not measured cannot be known. This leaves us with the unknown knowns, which are things we've measured but just don't know it. Unveiling these hidden knowns amounts to the holy grail of big data science and analytics. Finding them requires fusing data from multiple sources to create and exploit what data scientists call mutual information, meaning knowledge that can be divined only by combining information housed in discrete data sets, thus bringing to our awareness things that we may have unknowingly measured. View this as mapping from the unknown knowns to the known knowns.

Let's take a brief step back and underscore the fact that data exists everywhere in the universe. For example, we're in an environment saturated by signals, radio and such. Just because we are not aware of them doesn't mean they're not there. We don't care about all data. There are specific things we wish to know and the thing that determines whether or not the data in our environment is relevant to that is the question we ask of it. Once we pose a question, we can quantify the information content in said data related to the thing we wish to know. It may indeed be zero.

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Moriba Jah is an astrodynamicist, space environmentalist and associate professor of aerospace engineering and engineering mechanics at the University of Texas at Austin. He holds the Mrs. Pearlie Dashiell Henderson Centennial Fellowship in Engineering and is an AIAA fellow. He also hosts the monthly webcast "Moriba's Vox Populi" on SpaceWatch.global.


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