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NEW LIFE FOR THE B-52s

Re-engining competitors vie to keep these U.S. nuclear, conventional workhorses flying past 2050 PAGE 24

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On the cover: A B-52H Stratofortress takes off from Minot Air Force Base, N.D.

Image credit: U.S. Air Force

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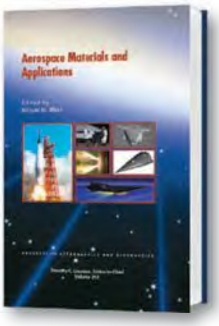

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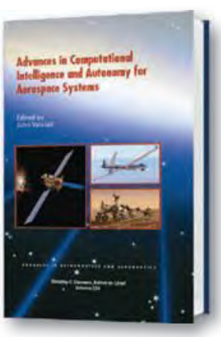

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AIAA
SHAPING THE FUTURE OF AEROSPACE

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AIAA SHAPING THE FUTURE OF AEROSPACE

IN THIS ISSUE

Amanda Miller

Amanda is a freelance reporter and editor based near Denver with 20 years of experience at weekly and daily publications.

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Jan Tegler

Jan covers a variety of subjects including defense for publications internationally. 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."

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Debra Werner

A frequent contributor to Aerospace America, Debra is also a West Coast correspondent for Space News.

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DEPARTMENTS

▲ The U.S. Air Force plans to install commercial jet engines on its B-52 Stratofortress fleet.

U.S. Air Force

Flying commercial

This issue of the magazine has me thinking about society's willingness to trust commercial technology for safe travels in air, orbit and deep space.

We're about to find out if B-52s manufactured in the 1960s can be made to fly safely for 100 years or more in part by installing commercial jet engines on them. The U.S. needs to get this one right to assure the effectiveness of the U.S. nuclear deterrence mission for decades to come, assuming humanity doesn't come to its senses and figure out how to banish these weapons.

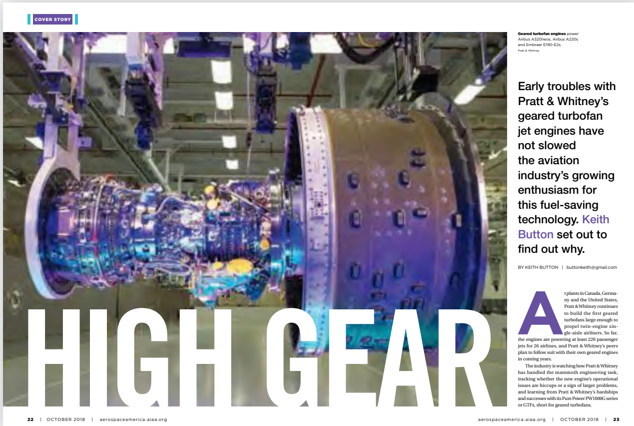
In other matters, we're about to learn if we can trust privately owned rockets and capsules to launch NASA astronauts and someday regular (if well-heeled) people into space. The Commercial Crew program represents an early start down that path. Our feature shows the stakes and the milestones that Boeing and SpaceX are facing this year.

My thinking is that we ought to be able to trust the private sector to perform well in this area, provided we set up a regulatory framework equivalent to the one that has made air travel so amazingly safe. Of course, a challenge is that reaching space and flying through it might always be more technically daunting and therefore risky than air travel. Launch costs could remain prohibitively high, because of the required safety measures. Those measures depend on humanity's risk tolerance for space travel, which I don't think we fully understand yet.

Even if launch costs and risks aren't slashed as much as hoped, all is not lost for scientific exploration and commercial exploitation of space. We might need to shift our definition of what constitutes a multi-planet species. Instead of millions of people living in lava tubes on Mars or aboard a village on the moon or digging at asteroids, perhaps handfuls of explorers and space tourists will venture out there to give humanity the emotional satisfaction of in-situ presence. Instead of robots preparing the way for us, maybe it will be the other way around. Market realities could drive humanity toward robotics, automation and augmented reality as means of establishing a permanent presence in deep space. We can accept higher risks when we send inanimate investments to deep space. Government researchers and commercial entrepreneurs are making so much progress on optical communications, artificial intelligence and virtual reality that such a shift might not be as disappointing as it seems today.

We're becoming extraterrestrials any way you look at it. ★

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


COVER STORY

Early troubles with Pratt & Whitney's geared turbofan jet engines have not slowed the aviation industry's growing enthusiasm for this fuel-saving technology. Keith Button set out to find out why.

HIGH GEAR

Straight talk about geared turbofans

I found the article "High Gear" [October] to be one-sided in some parts and uninformed in others.

The article was one-sided in that it did not give enough attention to the serious issues experienced by the first GTF [geared turbofan] customers. There have been real issues for Lufthansa, for example, at their Frankfurt, Germany, hub and these issues have been painful. Also, the article made a brief reference to the non-geared CFM LEAP Engine, but it should have noted that the LEAP introduction into service was considerably smoother than that of the GTF. In addition, while some better efficiencies are associated with a lighter-loaded GTF low-pressure turbine, there are inherent losses associated with the gearbox. These losses are magnified as one goes to larger power plants like the one needed for a Boeing NMA (New Mid-Market Airplane). After numerous (10 to 20?) years of development on the geared fan, the fuel-saving-technology advantage has not been demonstrated for the GTF.

The article also provided an incomplete description of the GE90's history, quoting someone calling the GE90 "an absolute pig, when introduced." The GE90 indeed had a number of teething problems in the *factory*, but it turned out to be the most reliable high bypass engine in the field. The proof is in the fact that with the original version of the Boeing 777 aircraft, there were three competing power plants. The power plant of choice on all subsequent versions of the Boeing 777, including the new 777 X, has been the GE90.

M.J. Benzakein
AIAA fellow
New Albany, Ohio

Editor's note: Benzakein was the chief engineer at General Electric Aircraft Engines for the GE90 engine program.

Turning Challenges into Success

I'm sure you remember, as I do, the first time you presented a research paper. It's a defining moment — the thought and hard work you put into your research with the intent of advancing the conversation. For many students, an AIAA Regional Student Paper Conference is the first opportunity for them to receive that all-important professional feedback on their research and presentation style. It's their first taste of presenting their own work and what it can mean to their careers and to the aerospace community.

I'm calling on you to support the AIAA Regional Student Paper Conferences and participate by working with students, who also may be able to teach you something new. Abstracts for many of the regional conferences are due this month and the Region I–Region VI conferences take place in March and April (aiaa.org/StudentConferences).

The student conference schedule is: 29–31 March in Austin, Texas, for Region IV; 4–5 April in Cocoa Beach, Florida, for Region II; 4–5 April in Minneapolis, Minnesota, for Region V; 5–7 April in Cleveland, Ohio, for Region III; 5–6 April 2019 in College Park, Maryland, for Region I; 6–7 April in San Luis Obispo, California, for Region VI.

If you can't attend a conference, reach out to student branches in your region to discuss your aerospace experiences. Students appreciate hearing your stories from the engineering and personal perspectives.

AIAA and the aerospace community are dedicated to developing a robust workforce and increasing diversity in the industry. We have complex challenges before us and need a variety of perspectives and experiences to develop the innovative solutions. I hope you met some of the Diversity Scholars at AIAA forums this year. Collaborating with AIAA's Diversity Working Group, the AIAA Foundation began this program last year. In 2018 we brought 70 students to AIAA forums and we are keeping the momentum going this year. Fifteen Diversity Scholars attended the 2019 AIAA SciTech Forum, which had record student attendance of almost 1,500!

As we concentrate on AIAA's 2018–2021 Strategic Plan goals, our clear mission is to help aerospace professionals and their organizations succeed. We'll be increasing our membership and engagement by using data to make solid decisions, leading in curated aerospace content, and being the authority in technology and capability advancement. We're focused on transformative flight, air mobility and autonomy, and the space ecosystem.

To accomplish this, we ask you to make your voice heard. **It's time to vote!** You'll be voting for a new President-Elect and openings on the AIAA Council of Directors. AIAA is fortunate to have such dedicated and qualified leaders who give their time and expertise to help this organization flourish. Your choices for President-Elect are: Basil Hassan of Sandia National Laboratories, George Nield of Commercial Space Technologies, LLC, and Wanda Sigur of Lockheed Martin Corporation (retired). Detailed information on the President-Elect and Council of Directors candidates can be found at aiaa.org/2019-AIAA-Election.

The 2019 AIAA SciTech Forum was a rousing success because of our members. When the federal government shut down and caused speakers, presenters, and attendees to cancel their plans, we sent out a call to the technical committees to fill the gaps. The TCs stepped up and then some. Thank you!

Even with the government shutdown, we had a record-breaking 4,500 attendees, including more than 1,400 undergraduate and graduate students. I learned more about how on demand is transforming aerospace. There were five plenary sessions, nine Forum 360s, and about 500 technical sessions, which featured more than 2,300 paper presentations. This year has begun with challenges and success, a fitting combination for aerospace. I'm looking forward to what's next!

Lastly, in October AIAA hosts the 70th International Astronautical Congress (IAC) in Washington, DC. The theme for the Congress is "The Power of the Past, the Promise of the Future." This annual gathering brings together the international space communities to discuss programmatic, technical, and policy issues. AIAA is honored to be the host organization. This will be a major opportunity for AIAA to demonstrate its ability to convene the experts and perspectives, It's also a chance for DC policymakers to see and touch spaceflight hardware and meet the experts. We look forward to seeing the AIAA membership at IAC 2019! ★

Have a great February!

Dan Dumbacher, AIAA Executive Director

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

Why don't airliners fly off into space?

Q. If a pilot attempted to fly his plane in a straight line for thousands of kilometers, rather than flying on a path parallel to the curve of the Earth, what would happen and why? How do pilots navigate from point A to B on a curved surface?

FROM THE JANUARY ISSUE

Q. We asked you whether a balloon-tour company that has never had an accident in its 98-year history should be seen as due for an accident. Reviewer Dave Finkleman, an AIAA lifetime fellow, thought the following answer was the best, although there is no simple answer.

A. Using statistics to weigh your future chances is risky — (almost) every casino visitor knows that.

In the current case choosing the referred company is not hazardous. On the contrary, it is recommended.

If a company has legacy which break the industry odds by almost two-folds, it is probably a good sign. The company itself might use this fact as a promotion in its marketing efforts:

"While the entire balloon industry suffers from lethal accident once in 50 years, we did not suffer such catastrophe in its last 98 year."

This is the main issue here, inferring future local possibilities while using global statistics is doomed to be wrong. The statistics refer to the entire balloon industry, while the current balloon firm is only a single player in this field. It is possible that the spotless legacy of such a company is based on excellence concerning safety which makes this firm a prominent candidate of balloon manufacturing.

On top of that, aerial accident probability can be referred as a memorylessness incident. In such cases the distribution of waiting time until a certain event, does not depend on how much time has elapsed already.

This is the reason why the man and his wife should favor the company in their quest of safe ballooning.

Ohad Gur, AIAA senior member; Shoham, Israel; 0hadg7@gmail.com

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

Planes, trains and satellites

BY DEBRA WERNER | werner.debra@gmail.com

Now that Iridium has finished launching its $3 billion constellation of next-generation communications satellites, the Virginia company's business partners are shifting from initial sales and beta testing to full-scale, revenue-generating services.

Consider Network Innovations, the Calgary, Alberta-based company that's one of the 30 or so around the world that have agreed to sell Iridium Certus, the broadband internet service that lies at the heart of Iridium's business plan for its Iridium NEXT satellites.

The Calgary company says it is feeling fresh demand since Iridium announced the official rollout of Certus on Jan. 16, just a few days after a SpaceX Falcon 9 rocket lifted off on Jan. 11 with the final tranche of 10 satellites, each about the size and weight of a Mini Cooper. All 66 Iridium NEXT satellites (and nine spares) are now in orbit with crosslink antennas that will route voice communications and high-speed data from satellite to satellite and to mobile customers on land, ships or aircraft.

Network Innovations had tested Iridium Certus with Rocky Mountaineer, a luxury train service with routes in the U.S. Pacific Northwest and Western Canada. The final tranche of satellites should achieve the data transfer speeds that train passengers require. Iridium expects the satellites in this last tranche to begin carrying communications in February.

If all goes as planned, train passengers will for the first time have "crystal clear" phone calls and high-speed internet links, says Eric Verheylewegen, executive vice president for Network Innovations. Cellular service for the passengers has been spotty due to the mountainous terrain, and the mountains ruled out relying on geostationary communications satellites that orbit over the equator. The company elected to wait for Iridium Certus, believing that it will deliver the desired coverage and speed.

▲ **Rocky Mountaineer** train passengers will have "crystal clear" phone calls and high-speed internet links, according to Network Innovations.
Rocky Mountaineer

Iridium's dozens of satellites will make "a big difference for clients who operate at high latitudes or in areas where a clear view to the equator is not always guaranteed," says Verheylewegen. "Certus is not the first mobile broadband satellite system but it is the only one that is truly global."

With the official start of the Iridium Certus service, "we are indeed getting more interest from clients who know the service is fully up and running," he adds.

The innovations aren't just on the satellite. The antenna terminals that access the network are smaller than Iridium's older terminals. Versions are manufactured by Cobham, Thales, Collins Aerospace, L3, Gogo and Satcom Direct. They will provide high-speed communications of up to 700 kilobits per second with the next firmware update. Also, they have no moving parts, and that's important to Rocky Mountaineer "because the vibration on trains is incredible," Verheylewegen says. ★

Forum Highlights

Airbus executive calls for patient tenacity in rollout of urban aircraft

▲ **Eduardo Dominguez Puerta**, head of Airbus' urban air mobility unit

Eduardo Dominguez Puerta, the head of Airbus' urban air mobility unit, offered in his keynote address, "Flying Anyone From Here to There — Anytime, Anywhere," a straightforward rallying cry: "Let's stop dreaming, and let's start making."

Dominguez Puerta said the mobility revolution will unfold in a step-by-step fashion that he compared to the rise of the computing and software industries. Thirty years ago, he said, there were "these weird people that try to write code and create source code for machines."

The revolution is "going to take time, and we need to be realistic," he said.

Helicopters, such as the company's Voom aircraft that take customers from Sao Paulo airport to the city center for $120 to $140, are a first step, he said, that will be followed by combustion-electric hybrids and eventually all-electric aircraft.

Dominguez Puerta said it should be possible to capture 3 to 5 percent of traffic from airports.

"That closes the business case," he said, "and doesn't take decades." Dominguez Puerta explained that he anticipates urban mobility mixing with other modes of transportation and complementing them.

Out of the dozens of designs in the works today by various companies, he expects the field to eventually narrow to five or six configurations or manufacturers. Also, the first aircraft in the emerging market won't be autonomous, he said.

"Why do I say that? If you read those draft regulations from [FAA and the European Aviation Safety Agency], they don't talk about autonomy," he said, adding that removing pilots and replacing them with customers is going to take until 2030.

— Ben Iannotta | beni@aiaa.org

"Buckle up: 2019's going to be busy."

— Chris Shank, U.S. Defense Department, Strategic Capabilities Office, on pending creation of the Space Development Agency

"We deeply believe that the final frontier — the space economy — is going to be opened by manufacturing."

— Andrew Rush, Made In Space president and CEO, predicting that on-orbit manufacturing will serve as the catalyst for the coming space economy

"You know what the most flexible robot is? A human being."

— Tony Gingiss, CEO of OneWeb Satellites

▲ **Amy Pritchett**, left, moderator and Department of Aerospace Engineering head, Pennsylvania State University; **Kathy de Paolo**, vice president of technology, Walt Disney Co.

Culture of innovation is key to being disrupter

The aerospace community must embrace a culture of innovation in order to harness the power of disruptive technologies, Kathy de Paolo, Disney's vice president of technology, said in her keynote address, "Applying Disruptive Technologies in Disney Parks, Experiences and Consumer Products."

From the "internet of things" to voice recognition technology to augmented reality to robotics, Disney has incorporated disruptive technologies throughout every facet of its organization.

"Technology is what powers the magic behind Disney," de Paolo said.

She said Disney helped pioneer these technologies, such as in 2013, when the company introduced internet of things into its parks with the Magic Band. The radio-frequency wearable allows guests to board shuttles, bypass lines, securely unlock their hotel rooms and pay for meals and photos.

De Paolo said connected devices are enabling context-aware computing on a new scale and constitute "a major enabler for autonomy and on-demand."

The "juggernaut" of disruptive technology, she noted, is artificial intelligence and machine learning. "Either way," de Paolo said, "we're talking about enabling levels of autonomy previously only imagined."

Machine learning applications are affecting every segment of every industry, de Paolo said, and organizations must keep up.

"This is not a game where you can sit comfortably on the sidelines and wait for emerging tech to become mainstream tech," she said.

— Lawrence Garrett | lawrenceg@aiaa.org

SCITECH FORUM

- **More than 4,000** Attendees
- **43** Countries registered
- **1,454** Students registered

Engineers recall working on Apollo program

▲ **Bill Widnall**, former director of control and flight dynamics at MIT Instrumentation Lab

During the "Engineering Apollo" panel, one of the 12 astronauts who walked on the moon and several engineers recounted what it was like working on the Apollo program computer systems.

Bill Widnall, former director of control and flight dynamics at MIT Instrumentation Lab, said he was in the right place at the right time.

"My first assignment as a research assistant was to develop the simulations that could be used to try out the flight software," he said, adding that he also came up with one failsafe used by the Apollo program. "I was very proud that I put into it the ability to use the lunar module to push the command service module."

Don Eyles, an author and a retired computer scientist who also worked at MIT Instrumentation Lab, said computers of that era were extremely slow.

"It took several hours to run one landing simulation," he said, adding that extra information from Earth radars was vital for landing accurately.

Eyles said some of the Apollo simulations ran on "hybrid" digital-analog computers. John Tylko, who teaches the Engineering Apollo course at MIT, explained, "At the time Apollo occurred, we were at this transition between analog and digital; and at the time, analog was faster."

NASA astronaut David Scott, who walked on the moon during the Apollo 15 mission, described what the digital transformation meant for the astronauts.

"We learned through their programming that we could do almost anything with this computer," he said. "It's actually amazing capability in the software to enable the operator to do all these things."

— Hannah Godofsky | hannahg@aiaa.org

"I don't think we should be scared about the surprises we're going to find. I think we should run toward them."

— Eduardo Dominguez Puerta of Airbus, regarding the rollout of urban air mobility craft

"We are one of the only industries that will dispose of billion-dollar assets after they're depleted of fuel."

— Alfred Tadros, vice president of Space Infrastructure and Civil Space at SSL, speaking on the need for on-orbit servicing

"How does this autonomy help us to be human?"

— James Cutler, associate professor of aerospace engineering, University of Michigan, on moral questions that come with development of autonomous systems

Autonomy, electrification are focuses of today's innovation

▲ **Gwen Lighter**, GoFly CEO and founder

The "Lindbergh Innovation Forum" showcased disruptive technologies from electric to supersonic that promise to transform aviation.

Erik Lindbergh, grandson of Charles Lindbergh and president of VerdeGo Aero, said education is one of the missions of the Lindbergh Foundation. He said the foundation in particular aims to keep middle school students — especially girls — interested in STEM.

Part of the work is fueling innovation as aviation enters an electric age, panelists said. GoFly, a Boeing-sponsored competition, is offering a $2 million prize for the best design of a safe, quiet, ultra-compact and near-vertical takeoff and landing aircraft capable of carrying a single person for 20 miles without refueling or recharging. AIAA is one of the competition's partners.

Prizes such as DARPA's Grand Challenge, which pushed autonomous vehicles, have spurred innovation, said Gwen Lighter, GoFly CEO and founder. Phase 3 of the GoFly competition will be later this year, she said.

Electrification and autonomy were common threads for the Lindbergh Innovation Forum.

"Autonomy increases the access to flying machines," said Brian Yutko, senior vice president of programs at Aurora Flight Sciences, a Boeing company. "Electric propulsion increases the access to more types of flying machines."

Supersonic is making a comeback, although with a quieter and more efficient profile than the Concorde, the first supersonic passenger-carrying commercial plane, said Michael Hinderberger, senior vice president of aircraft development at Aerion Corp.

The new supersonic plane is designed to be fast, efficient and luxurious, with an initial eye on the elite business traveler.

— Michele McDonald | michelem@aiaa.org

Forum Highlights

Metal 3D printing to become routine tool

▲ **Mohammad Ehteshami**, retired CEO and vice president of Additive Integration at GE Aviation

Panelists in the "On-Demand Metal Manufacturing" session discussed the current state of metal additive manufacturing, its challenges and where it's headed.

For Mohammad Ehteshami, retired CEO and vice president of Additive Integration at GE Aviation, the turning point came when GE decided to print an engine fuel nozzle using additive manufacturing.

"We created because we had to," he said. "It was fight or surrender."

Before additive manufacturing, the nozzle had 25 parts and traveled 5,000 to 10,000 miles during the manufacturing process, Ehteshami said, explaining that now, it is one part and travels 100 meters from start to finish.

Panelists said they expect metal additive manufacturing to become another useful tool. However, they said, until then, some challenges, including not sharing information, may hamper the process. In the earlier stages of additive manufacturing, companies didn't share because they wanted to hold onto competitive advantages. Now the advantage is setting standards for what works.

Workforce development is another hurdle for metal additive manufacturing. Knowing the phases of the manufacturing process helps ensure success. Panelists noted that skilled members of their teams are multidisciplinary.

Panelists agreed that metal additive manufacturing is at a transition, with the expectation of it becoming another useful tool. Martian soil could provide the basic materials to print what space explorers need, and additive manufacturing could turn discarded metal in landfills into products, said Randall "Ty" Pollak, director of research and development with Universal Technology Corp.

"There's gold in those landfills," Pollak said.

— Michele McDonald | michelem@aiaa.org

"This is not a game where you can sit comfortably on the sidelines and wait for emerging tech to become mainstream tech."

— Kathy de Paolo, Disney's vice president of technology

"As engineers, we're system integrators for a large part. That means we need mechanical engineers, electrical engineers, lots of different types of engineering and technical backgrounds."

— Tamaira Ross, principal manager, New Glenn System Definition and Design, Blue Origin, on the need for technical diversity in the aerospace workforce

On-orbit manufacturing could open final frontier

Experts in the "In-Space Factories" panel discussed advanced technologies and collaborations between government and private industry that promise to establish on-orbit assembly, manufacturing and servicing as the backbone of a new space economy.

▲ **Tom Cwik,** manager of the Space Technology Program and Ocean Worlds Technology at NASA's Jet Propulsion Laboratory

Tom Cwik, manager of the Space Technology Program and Ocean Worlds Technology at NASA's Jet Propulsion Laboratory, said on-orbit assembly is a viable solution to the longstanding challenge of limited payload capacities of launch vehicles.

Alfred Tadros, vice president of Space Infrastructure and Civil Space at SSL, said that while today's on-orbit satellite operations consist of mostly fixed assets, future ones must depend on serviced assets capable of being upgraded, relocated, repaired and refueled.

"We are one of the only industries that will dispose of billion-dollar assets after they're depleted of fuel, even if there's residual capability remaining," Tadros said.

He said SSL is collaborating with NASA and DARPA on separate projects aimed at advancing critical technologies in satellite servicing and exploration.

"It is the intention of DARPA and the U.S. government to motivate, incentivize, tear down technical barriers, regulatory barriers and perception barriers, in order to make this kind of complex on-orbit servicing a reality," Tadros said.

Robert Hoyt, CEO of Tethers Unlimited Inc., said one of the primary challenges in growing the new space economy is determining how to get the needed materials into space. He cited his company's Refabricator project as one solution. Refabricator is a recycling and 3D-printing system launched to the International Space Station in November.

— Lawrence Garrett | lawrenceg@aiaa.org

▲ **Aaron Kahn**, U.S. Naval Research Lab flight controls engineer

From rockets to gliders, autonomy finding its fit

Panelists in the "Autonomy Across Domains" session discussed how autonomy is working behind the scenes in vehicles as disparate as space-bound rockets, Vietnam-era military helicopters and balsawood gliders.

"The magic here is hard to show," said Amy Pritchett, professor and head of the Department of Aerospace Engineering at Pennsylvania State University.

Autonomy can accomplish tasks that would otherwise be impossible, said James Cutler, associate professor of aerospace engineering at the University of Michigan. For example, autonomous systems can handle landing in a dark crater on an asteroid, which can't be mapped in advance, or can control vehicles on Mars, despite an approximate 20-minute communications delay to Earth.

"You can't joystick or control anything that far away," Cutler said.

There are more than 80 programs and 400-plus vehicles at the U.S. Naval Research Lab, said Aaron Kahn, flight controls engineer at the lab. The autonomous vehicles are designed to be deployed by ship, air or air to water.

One such vehicle is a fully autonomous, electric coaxial helicopter that launches from a tube and looks like a flying fence post. It has 10 seconds to figure out which way is up, unfold and become an aircraft.

Another is a glider and, like Buzz Lightyear, "it falls with style" Kahn said.

— Michele McDonald | michelem@aiaa.org

"I think it's really difficult to offer a high-touch education through some types of e-learning."

— Eric Paterson, head of Virginia Tech's Department of Aerospace and Ocean Engineering, on the advantage of in-person education versus distance learning

"Autonomy increases the access to flying machines. Electric propulsion increases the access to more types of flying machines."

— Brian Yutko, senior vice president of programs, Aurora Flight Sciences

"We created because we had to. It was fight or surrender."

— Mohammad Ehteshami, vice president and retired CEO, Additive Integration, GE Aviation, on GE's additively manufacturing an engine fuel nozzle

Complex systems changing workforce requirements

Panelists in the "Workforce Needs of the 21st Century" session highlighted the necessity for more innovative, creative and adaptive engineers to meet the dynamic and accelerating challenges of the future.

▲ **Stephen Morford**, vice president, Pratt & Whitney's Core Systems Engineering

Dan Dumbacher, AIAA executive director, said it was during his time at NASA that he first noticed the changing educational requirements needed to meet the future demands of the aerospace industry. He said the discussion is vital today to help the younger generation in particular.

"I find it extremely important that we have this conversation and look at what is needed in the industry so that … our educational system can be changed up," Dumbacher said.

Tim Cahill, vice president of Integrated Air and Missile Defense at Lockheed Martin Missiles and Fire Control, said one of the primary challenges is the growing complexity of systems with more and more integration. He also cited the accelerated pace of that growth. "There's just not time to react," he said.

Cahill said the biggest need in his organization is for system engineers, simulation engineers and "folks [who] know how to put those big systems together in ways that make them effective."

Stephen Morford, vice president of Core Systems Engineering at Pratt & Whitney, agreed with Cahill on the growing importance of complex systems integration and said that aerospace engineers need to "start thinking as system engineers," capable of working in cognitive command and control environments and knowledgeable about the connectivity of today's aircraft.

"When I look at airplanes, connectivity of systems is greater than it ever has been, and it's only going to get better and better," he said.

— Lawrence Garrett | lawrenceg@aiaa.org

OneWeb Satellites CEO Tony Gingiss
AIAA

Mass producer

More online aerospace america.aiaa.org

OneWeb Ltd.'s vision of spreading broadband communications around the globe will require mass producing hundreds of 150-kilogram satellites. A little over three years ago, OneWeb and Airbus established a separate joint venture, OneWeb Satellites, to make satellites for the main OneWeb company and someday other customers too. The first satellites produced by this venture are scheduled for launch this month on an Arianespace Soyuz rocket. The next challenge will be to accelerate production from the 10 satellites built so far to about two a day or 35 to 40 per month. This will be done at a newly built manufacturing facility in Florida. For details, I spoke to Tony Gingiss, CEO of OneWeb Satellites, during last month's AIAA SciTech Forum.

— Ben Iannotta

TONY GINGISS

POSITIONS: Since September 2017, CEO of OneWeb Satellites, the joint venture formed by OneWeb Ltd. and Airbus in 2015 to mass produce satellites for OneWeb's broadband constellation and eventually other customers. From June to September 2017, vice president for the constellation's space segment at one OneWeb Ltd. In a 14-year career at Boeing, rose to director for strategic integration of satellite systems.

NOTABLE: At Boeing, led the team of 140 engineers that got production of the GPS 2F satellites on track. "We were perpetually 18 months from launch," Gingiss recalls. He led the team through 2011 and the launch of first two satellites. Joined OneWeb Ltd. of Florida in 2017, not knowing that a few months later he would be asked to become CEO of the sister production company, OneWeb Satellites. Spends much of his time shuttling between his home in California and production facilities in Florida and Toulouse, France.

AGE: 49

RESIDES: Sierra Madre, California

EDUCATION: Bachelor of Science in aeronautical and astronautical engineering from Purdue University in 1990; Master's in aeronautics and astronautics from MIT in 1992.

IN HIS WORDS

Balancing risks of failure

... I gave a great analogy to someone yesterday. We were talking at dinner, and I said, "When drones first came out, private drones, I bought one for like $400." OK, I'm an engineer, so I'm inherently probably a little thrifty in that I don't want to break this expensive toy that I bought. I had the HD camera and everything, and you could fly it. I was always very cautious with it. I'd fly it and I had fun, but I didn't want it to get too far away. I didn't want to crash it into a tree. I didn't want to get it stuck somewhere. It's 400 bucks. I didn't want to break it and have to rebuild it. It was fun, but it was never quite the fun that I thought it was. Then, someone bought me a $29 micro drone, a quadcopter little thing. No camera but a little controller. Twenty-nine bucks. I'm like a madman with it. I'm willing to take more risk. Every time I crashed I was thinking, "Oh. That's $400." It's like, "Oh, if I crash, it comes with this little spare bag of parts that I bought for 6 bucks. If I really destroy it, it's $29." I have more fun with that thing, and I learned how to be a better drone pilot with that than I did with the $400 one with all the additional fancy technology, because my risk equation was different. I actually think that analogy applies to what we're doing in the space industry today.

I've worked on programs that took decades to build and cost things that didn't have millions of dollars but had billions of dollars after them, and those weren't zero-risk either. Nothing we do in our business — nothing you do in life — is zero-risk. It's about managing risk. When you spend a billion dollars on something or $500 million on something and you'd spent 10 years of your life and government dollars or private dollars or people's time, the risk you're willing to take that something may be a step too far is going to be very different than if you spent sub-$10 million for one or two of them, and you just spent 12 months developing it.

Averting creation of orbital debris

We've put a lot of work into making sure that these satellites, ultimately, are de-orbitable. The highest reliability number we have for the satellite is de-orbit reliability. It's the most important thing. Even higher than our mission availability. The avionics and the Hall-effect thruster propulsion system [have to work], and we have a very high reliability that we have for that. The UK Space Agency is kind of who OneWeb works through for getting all their launch licenses, so that's something they've been very keenly aware of and interested in.

Emergency handle

We actually designed-in what we call a grapple fixture. It's essentially a fixture that ties into the main structure of the vehicle. It's physically kind of a knob, if you will, that you can actually grab if you had a service recovery vehicle. You could actually go pull a dead satellite down. We've designed that in as a backup capability. Should we ever need that, there would always be a way to capture that satellite and bring it back down. That was designed to be tied right into the structure so it could withstand that pulling force, and not pull the satellite apart, which would be worse.

I'd say we've put a lot of thought into [de-orbiting] right upfront. Plus, we've put in kind of these backup plans should we ever need some capability like that. That [on-orbit servicing] industry doesn't yet exist, but we're trying to pre-position ourselves and our customers with hardware. That was proven hardware that have been used for things, so that as those capabilities evolve, they could use them if they ever needed to.

"We've put a lot of work into making sure that these satellites, ultimately, are de-orbitable. The highest reliability number we have for the satellite is de-orbit reliability. It's the most important thing. Even higher than our mission availability."

Price

I think way early on, there was a lot of talk of a half-a-million-dollar satellite. OneWeb basically confirmed at EuroConsult that they're paying under a million dollars for a satellite. And they're buying 900 of them. That's kind of the price point when you have a proven design, and we've gone through it, and you're buying a very large quantity. I've always said if people want a price point, we're talking about low-digit, single millions of dollars. Sub-$5 million for a satellite that's, in some cases, an eighth the capacity of a geo communications satellite; a fraction of the weight, a pretty significant fraction of the comm capability, and one-one-hundredth the price, in some cases.

Satellite mass

They're right at about 150 [kilograms], but we've been working very closely with [OneWeb] because we want to give them the best capability to launch as many as possible. And if we can save a couple kilograms a satellite, that may mean the difference between them getting 36 on a vehicle versus 34 or 32.

Facilities in Florida and Toulouse

When we're done with Florida, we will have three production lines. We'll have one in Toulouse and two in Florida. The Florida facility is a ground-up facility. So in the design contract for OneWeb, we've qualified the satellite design. That's what we're finishing up right now. We built the first 10 vehicles, and we essentially designed and proved out the production system in Toulouse, France, right on the edge of the Airbus facility. We have our own building.

The Florida facility is actually a clone of that production system. We've proven it out over there. We clone it and basically make a times-two version of it. The Florida building is probably about four or five times larger than what it is in Toulouse. We were a little space constrained there because we were dealing with an existing building. The Florida facility is a ground-up facility with two complete factory assembly lines. That's four module stations

Appearing at the 2019 AIAA SciTech Forum, from left, Heather Bulk, Special Aerospace Services; Tony Gingiss, OneWeb Satellites; Robert Gold, U.S. Defense Department; and Jeff Miller, Boeing.
AIAA

each with two full final assembly lines where we bring all the modules together and integrate vehicles, sized, basically, to do two satellites a day.

Assembly line commissioning

We're actually going through what we call commissioning right now of the factory assembly line. We're running real flight hardware through the first line. And the second line will be up about a month behind that. First line should be up and producing modules starting in March, and the second line will be up roughly a month later than that, producing module-level assemblies. Then we'll have vehicles coming out starting a few months later starting all the way through the first batch.

Assembling modules

We have four module stations. We have a propulsion module, which is basically the propulsion tank and the thruster. We have an avionics module, which is pretty much what you think of as the bus. It has all of the star trackers, and the wheels, and the flight computer, and that kind of thing. Most of it is on a single panel. Then we have a payload module, which is actually several panels. It's kind of the front payload Ku antenna and the side payload panels. Then we have the solar array modules or the solar wings, essentially. So, all of those things together create kind of the web-shaped cube that you see as our vehicle, and every module is assembled, basically, in a single shift. Then final assembly of all of those together is less than an eight-hour shift. So, if you think every shift you're producing one — and on a single factory assembly line — you're producing one of every type module and integrating a whole vehicle.

Testing

We have test chambers. We call them Day-in-the-Life chambers, or diddle [DITL] chambers, where we do thermal cycling. We do that for a period of one to two weeks in that order. Then we have connectivity cabins where we actually power the whole spacecraft with light, as you test as you fly. Power them up as they would be in orbit, and actually do SOC [satellite operations center] connectivity with the customer side.

The scene in Florida

It's pretty exciting. I mean Blue Origin was a little ahead of us in terms of build. I think we'll go into production first, with building little smaller things in there. They've been great neighbors. They're right across the street. At Space Florida a lot of companies have labs and stuff in that facility. They're literally just half a block, a block from us. So, basically, in that one little area, there's the big Space Florida building, us and Blue Origin.

Staffing up

We are hiring. Our big push now is we're kind of finishing up the design phase. Florida is really focused on production, so we are hiring, basically, people to staff our factory. We will be hiring some engineers, but again, the near-term stuff is not really an engineering problem. It's a production focus, so we'll be hiring probably roughly 100 to 110 people just within the next six months. We're right at about 170 people right now, where roughly 90 of them are in Toulouse and the rest of them are in Florida. But by the time we get into full production, we'll be at basically 250 whereas Toulouse will kind of stabilize and maybe even go down as we exit the production phase at least in the near-term. Then, Florida will ramp up with staffing essentially two production lines. It's about

“People ask me: ‘Why haven’t we invested more heavily in robots?’ I said we’ve looked at it, and for the dollars, it was cheaper to buy and have skilled technicians do certain things than to go invest in robots and go that way. They’re not as easy to adapt as we probably need them to be. The cost-benefit just wasn’t there for us.”

90 people to staff both production lines at a single shift, kind of full staffing. So, just right there, you have roughly 100 people just staffing the floor.

Role of Toulouse vs. Florida

OneWeb is nominally slated to be all produced in the U.S. once we get done with the first 10. Production in Toulouse really will be for what we call third-party sales. So, Airbus has the third-party sales rights, and if they’re selling into Europe, we would probably produce over in Toulouse. If we’re selling the U.S., whether it be a [DARPA] Blackjack or some other commercial customer, we would ultimately probably produce that here in the U.S. at one of our two production lines here. So, we’ll maintain all three production lines as production. It’s really about: If we built it there for a customer there, why would we build it here and then ship it across the Atlantic? The other thing is we fully expect that we’ll have things for certain customers who will want it to be done in the U.S., and there will be certain things that certain customers in Europe will want to be done in Europe.

Satellites to date

By the time we get into February, we’ll be done with all 10 [required initially], and we’ll be ramping up Florida.

Proven technology

People ask me, “Oh, is the satellite cutting-edge?” I said, “If you just look at our satellite, there’s nothing about it that you say, ‘I’ve never seen this technology before.’” I would actually argue that, similarly, with our production system, there’s nothing that I would call bleeding-edge. We wanted proven technology. Things that we knew worked. I think that what’s really novel about what we’ve done is that if you look at the price point that we’ve established for our design, for the kind of quality that we’re providing, but the price point and the schedule for the design is unmatched. I mean no one’s ever done it for this, at this kind of production quantity; at the price point we’re at and at the speed.

Automated inspection

We actually have a series of cameras at each of the module stations. As you go through, all of the work instructions we have are digital. We don’t have any paper on our floor. No logging or anything. That’s all done automatically. When the operators are done with certain steps, they can actually manipulate 3D models if they wanted to see a different view of what they’re doing. Many of our work instructions have visual models, where it’s actually showing them what to do. They’re looking at computer screens suspended right in front of their face above and off to the side of one of the module stations where they’re working. There’s a series of cameras that sweep across the module that they’re assembling, and it compares that to, essentially, CAD renditions, I’ll call it for a lack of a better term. It looks for: Are all the parts installed correctly? Is something backward? Is something missing? Does something look out of tolerance? And, you know, your goal is to get to 100 percent automated visual inspection. We’re not there. We’re probably into mid ’90s. In some cases, maybe higher. Some modules, it’s more complicated because there’s variations we have to account for, but we’ve achieved a really high level of automated visual inspection. It’ll flag things and say, “This is not right. Either something’s missing here, or something’s not installed correctly.” And it’ll actually flag it for the operator on the screen, show them where the problem is, and it will not let them continue until they resolve the issue.

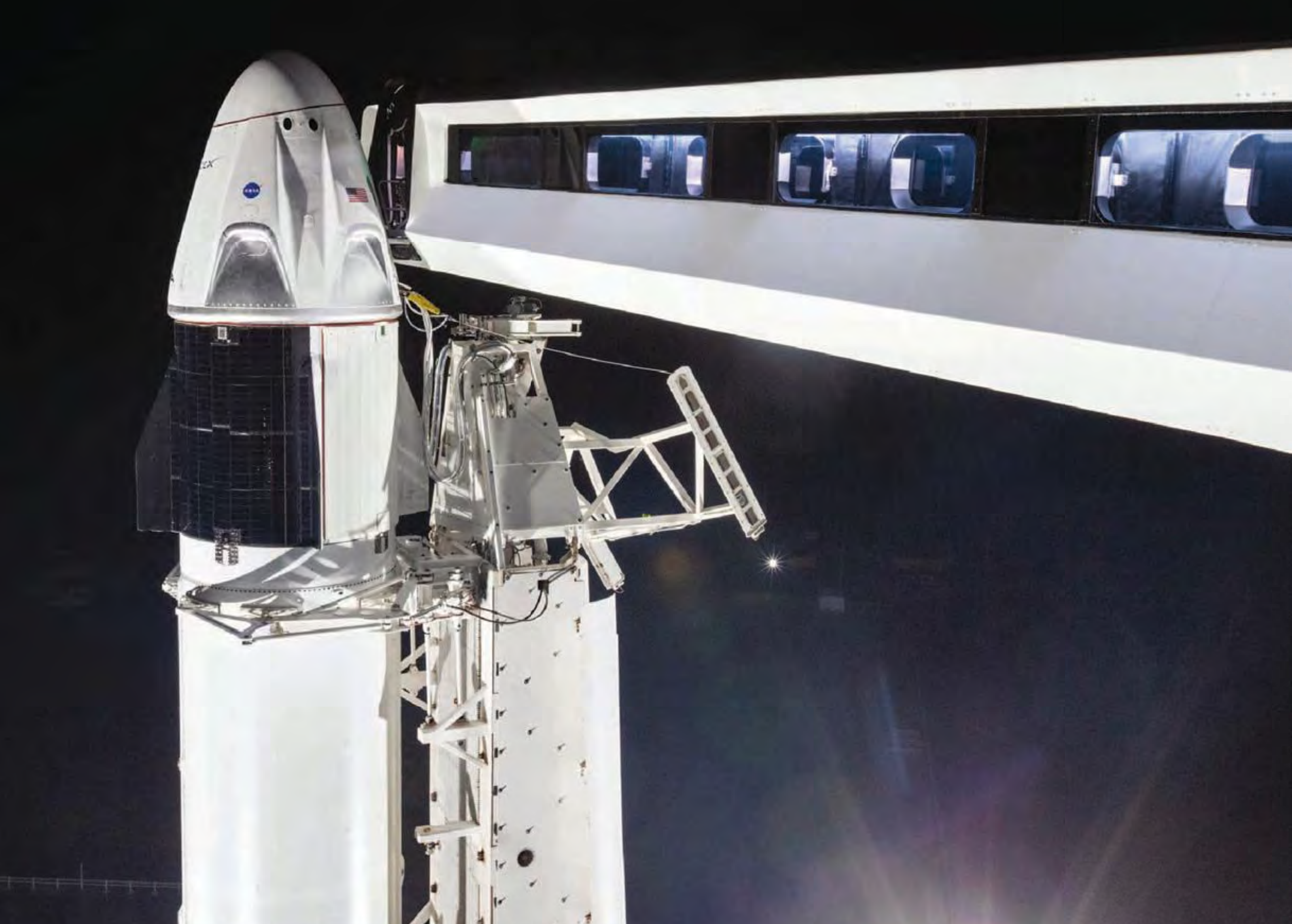
Down on robots

People ask me: “Why haven’t we invested more heavily in robots?” I said we’ve looked at it, and for the dollars, it was cheaper to buy and have skilled technicians do certain things than to go invest in robots and go that way. They’re not as easy to adapt as we probably need them to be. The cost-benefit just wasn’t there for us. So, everything we look at is: 1) We want it proven. It’s not that we don’t want it leading-edge, but we don’t want it bleeding-edge. We want to make sure that they’re actually meeting our needs, and we’re very, very conscious about cost and schedule, and then maintaining quality at the end. So, it’s a fine balance.

Limited use of additive manufacturing

We actually don’t do a lot of additive manufacturing. We’ve used it in a couple of areas where we think for tooling or other things it’s helpful. It hasn’t been a big unlocking thing for us that it’s allowed us to do something we couldn’t do otherwise. It’s something we continue to look at because some suppliers will come back and say, “Hey, I could do the next generation of this with additive manufacturing and maybe bring the price down a little more or increase the volume of our production, or whatever.” So, I think we’re always looking at it as a tool, but in and of itself, it hasn’t been a thing that’s unlocked our ability to do what we’ve done. ★

COUNTDOWN TO COMMERCIAL CREW



Boeing and SpaceX are poised to make 2019 the breakthrough year in the nearly decadelong effort to get the U.S. back in the business of launching astronauts to the space station and bringing them home. Amanda Miller looks at the stakes and steps ahead for the Commercial Crew program.

BY AMANDA MILLER | agmiller@outlook.com

SpaceX moved its Crew Dragon capsule and a Falcon 9 rocket to Launch Complex 39A at Kennedy Space Center in January to prepare for the planned crewless test mission to the International Space Station under NASA's Commercial Crew program. This photo was taken during a dry run and shows the access bridge that astronauts will someday walk across to access Crew Dragon.
SpaceX

The passengers queuing up on the platform include a scientist, a business mogul, a politician. They're privileged pioneers — private citizens prepared to rumble away on one of the newfangled conveyances that the transportation tycoons have started selling tickets for.

And they've all been issued matching suits.

It's someday in the future. They climb aboard from a platform 60 meters off the ground. They're headed to a commercial hotel in Earth orbit, then on to their final destinations — public and private space stations and in-space manufacturing plants.

Depending on the ride they've chosen, they may or may not linger on the "crew access arm" for a last look at the Atlantic Ocean along Florida's Space Coast. The designs of these arms aren't equal; one company's may harken back to a windowless airline boarding ramp while another's evokes the helm of a yacht.

This year, 2019, is supposed to be when NASA's combined $8.2 billion in grants under the 9-year-old Commercial Crew program — largely to Boeing and SpaceX — starts to pay off. The first crew launches by these companies would be a small step toward that futuristic vision and a big step toward liberating NASA from the Russian Soyuz capsules it has relied on to carry its astronauts to and from the International Space Station since 2011, when it retired the space shuttle fleet.

If the year brings a breakthrough, it will come two years later than planned and on the heels of a close call with tragedy in October, when a U.S. astronaut and cosmonaut made a hair-raising emergency Soyuz landing shortly after launch. By that time, the U.S. was not supposed to have needed a ride on a Soyuz. The companies had initially said that by 2017 they could get their respective spacecraft certified by NASA for human flight.

"If there are further delays," NASA associate administrator Steve Jurczyk told me in November, before the U.S. government shutdown, "we might have to buy one or more Soyuz seats for more time." The Government Accountability Office, in a 2018 report, "Plan Needed to Ensure Uninterrupted Access to the International Space Station," stated that NASA had contracted for seats on Soyuz spacecraft through a November 2019 return flight.

"The plan was always, when SpaceX and Boeing put their capability in place that we would discontinue buying Soyuz seats from Russia," Jurczyk said.

If all goes well, however, Boeing and SpaceX will take the final, critical steps this year toward earning NASA's human-rating certification for passenger spaceflight. This requires a number of benchmarks, including showing a "loss of crew" probability of 1 in 270 or lower. Each company must launch an unmanned version of its seven-person capsule to the space station, followed by a flight with a crew of two in SpaceX's case and three in Boeing's case. SpaceX plans to send its first capsule to the station no earlier than February, followed by the first crew launch in June. Boeing is targeting its first station launch for March on a United Launch Alliance Atlas 5 rocket followed by the first launch with a crew in August.

NASA has paid for much of the two capsules' development. But unlike in the past, the government won't take over the controls once these spaceships are all set to go. Boeing and SpaceX get to keep their spacecraft.

As interested as NASA is in getting the U.S. flying to space again, the agency doesn't want to forget the broader goal of establishing privately owned transportation to low Earth orbit. The thinking is that this could give a boost to those who envision creating privately owned space stations as the seeds of a vibrant economy in space.

"I know [the Commercial Crew contractors] are working with the companies, particularly Bigelow and Axiom, who have these plans for commercial laboratories, commercial hotels for space tourism, and how they could provide the transportation for those ventures," Jurczyk said.

How we got here

At a meeting in Denver in December, at which industry executives described their work in the field of human spaceflight, Joe Rice, director of government relations for Lockheed Martin Space, put today's scenario in perspective.

"Let me first impress upon you something that I think is a tragedy," said Rice, a retired U.S. Army colonel who has taught college-level history. "Since the dawn of the Space Age, there have always been two nations that could put people into space — going back to the '50s and the space race, always two nations that could put people into space. The Soviet Union and the United States — us. So today, this very day, there are still two nations that can put people into space, but the United States is not one of them," he said, referring to China and Russia. "And that should shock us and bother us."

As a staff member in the White House Office of Science and Technology Policy under President Barack Obama, Phil Larson worked closely with NASA to come up with the Commercial Crew plan as a follow-on to the George W. Bush administration's Commercial Orbital Transportation Services program. COTS paid companies to develop their ideas for commercially operated delivery services to the ISS, for both cargo and crew.

▲ **NASA, Boeing and** United Launch Alliance practice prelaunch routines in the Boeing Mockup Trainer for the Starliner spacecraft in Houston.
NASA

▲▲ **NASA simulates** a land landing with a mock-up of the Boeing CST-100 Starliner spacecraft at NASA's Langley Research Center in Hampton, Va.
NASA

The Commercial Crew program spun off COTS in 2010, outlining the specifics required for human transport. NASA's $8.2 billion for Commercial Crew is paid in increments, according to program milestones, while the companies also invested in the development. Larson, an expert on space politics and the assistant dean of the College of Engineering at the University of Colorado, thinks that the program will have been worth it even if the two capsules only manage to transport U.S. astronauts to the ISS. By reducing launch costs by "dimes on the dollar compared to what it was before," NASA will have proved that it "works" for the government to act as a venture capitalist.

Commercial Crew was always supposed to be about more than just supplying an astronaut delivery service to the government. The chosen companies also committed to cultivating new commercial markets with their spacecraft — "and then the cost of further developing and operating those vehicles would be spread across a business base that was more than just NASA," says Jurczyk.

Where things stand

Boeing engineers were readying a test vehicle for a test of Starliner's pad-abort escape system in White Sands, New Mexico, in early 2019, a delay following the discovery of a propellant leak in an earlier engine test. Meanwhile, the capsule for the company's first crewed launch was bound for Boeing's environmental test team in El Segundo, California. There, it would be exposed to simulated environments of launch and space and help to prove to NASA that it's safe for humans.

NASA astronaut Doug Hurley was one of the two astronauts selected to ride in a Crew Dragon on its first test flight with a crew. The former U.S. Marine Corps test pilot who piloted the space shuttle twice describes the preparations, in a NASA interview, as "relearning" all the procedures and techniques that go along with first-time missions on new spacecraft.

Both Starliner and Crew Dragon may look familiar. Starliner's shape harkens to the Apollo command module design, while Crew Dragon's spaceflight heritage is the cargo version that has flown 16 trips to the station and back. In fact, SpaceX's autonomous Dragon was the first private spacecraft to make a delivery to the ISS and back under a Commercial Resupply Services contract, NASA's earlier spinoff of COTS. That program has already resulted in numerous commercial deliveries and gone through a second round of contract bids.

The first Crew Dragon headed for space was on the launchpad at Kennedy Space Center as of last month — the pad where the space shuttles launched. This first test flight to the ISS had been delayed twice since NASA started giving dates in November 2018, this time "to complete hardware testing and joint reviews," according to a NASA statement.

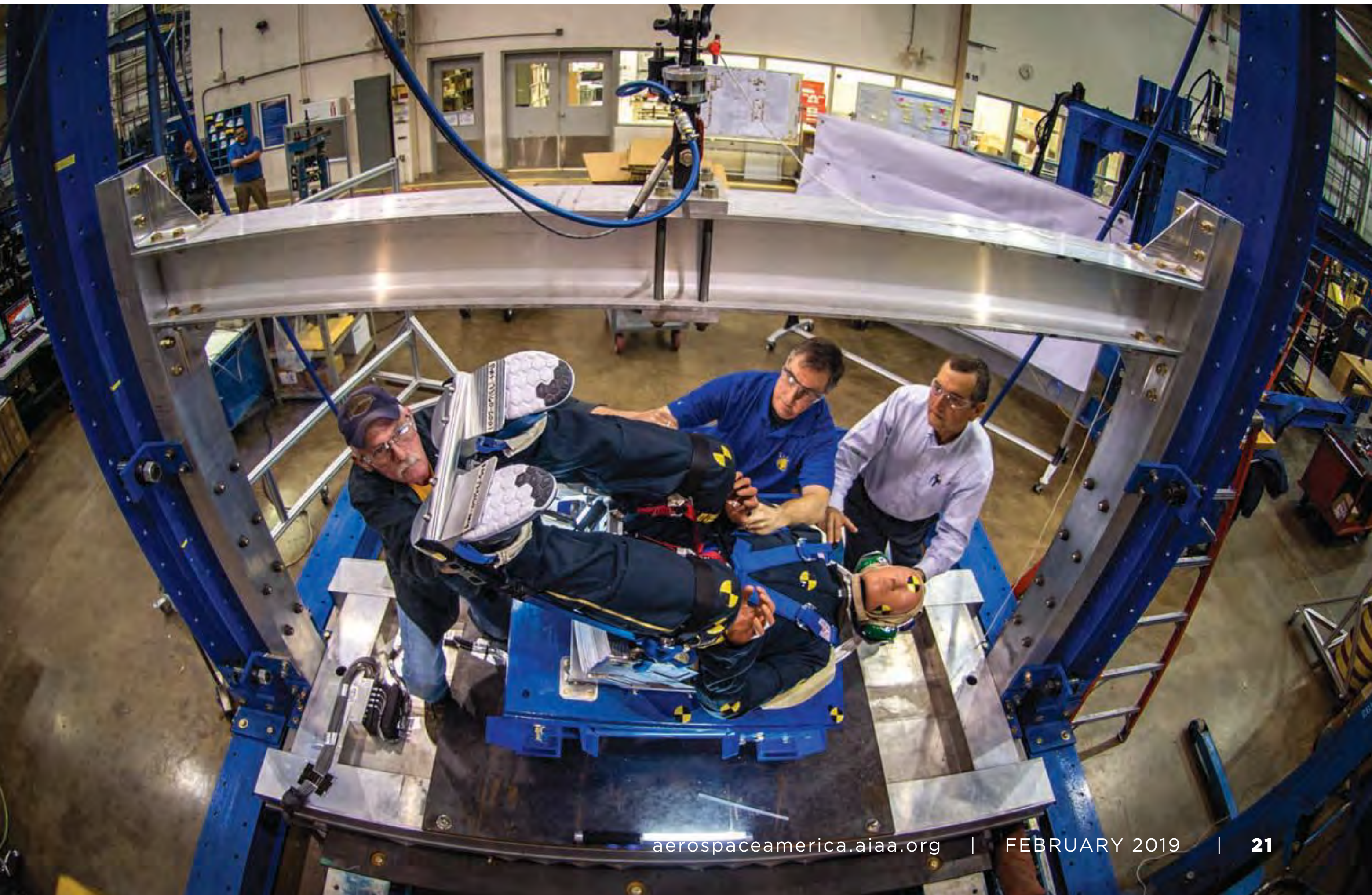
SpaceX will get astronauts to the ISS first, if the rest of NASA's launch timeline sticks, but only by a couple of months. Neither the SpaceX Falcon 9 design that will loft Crew Dragon nor the ULA Atlas 5 that will launch Starliner have ever carried people, which is why each must still be certified for human spaceflight.

ULA's Commercial Crew Program Manager Barb Egan said in late January that the Atlas 5 booster for Starliner's March test flight was ready for the launchpad and that the rest of the rocket was on schedule. A key addition to the human-rated Atlas 5 design is an emergency detection system to alert Starliner's flight computer if it needs to abort.

The crew won't manually fly either seven-person capsule. Both will be programmed to get to the space station, dock, then return to Earth autonomously, though astronauts can take over.

While the two spacecraft may seem familiar, the astronauts' personal gear is getting an outwardly

▼ **Engineers test the seat design** of Boeing's CST-100 Starliner in Mesa, Ariz.
NASA



apparent update. Starliner's crew will wear bright "Boeing Blue" spacesuits for launch, ascent and re-entry. Dragon's crew will get tinted faceplates with sleek, white-and-gray suits that coordinate with the look of the pod.

Situation with Russia

In the context of ISS crew rotations, delays can add up in increments of $80 million per flight. That's how much the Russian space agency, Roscosmos, charges to deliver U.S. astronauts back and forth in a Soyuz capsule, like the one in which the astronaut and cosmonaut had to abort in October.

Roscosmos' investigation found that during assembly, a pin was damaged on a sensor that controlled the separation of a booster. Both Crew Dragon and Starliner also will have the ability to separate from the rocket, fire engines to get away and land safely.

"Thank goodness the Russians put that capability in place eight or nine years ago for that scenario," says Jurczyk. "And it's challenging because that capability needs to work on the pad, when you're at zero speed, and then it needs to work when you're lower and slower in the atmosphere, and then it needs to work when you're higher in the upper atmosphere where it's less dense but you're going at a much higher speed."

LANDING TECHNIQUES

Starliner cushions its hard-surface landing with bottom-side airbags. SpaceX originally proposed a thruster descent to put down Crew Dragon on dry land, but later opted for an ocean splashdown. SpaceX founder Elon Musk said in a January tweet that the company de-prioritized the thruster landing after concluding that Crew Dragon would never go to the moon or Mars, where it would need to make a soft landing on thrusters.

Boeing designed the Starliner's mission in 10-second increments and calculates the probability of successfully aborting at 95 percent.

NASA had hoped to receive all human rating data back in 2017. In the GAO report, the congressional watchdog laid responsibility for the delays partly on NASA for allegedly giving unclear instructions about how to calculate the probability that an astronaut will die or become permanently disabled, the factor called loss of crew; and pointed out that the close involvement of NASA had taken more time than the companies had expected.

The GAO recommended that NASA, meanwhile, consider alternatives to the Commercial Crew vehicles for getting U.S. astronauts to the orbiting lab.

What a win looks like

Getting astronaut launches back underway from the U.S. could help restore the U.S. "geopolitical soft power" that Ian Christensen of the Secure World Foundation says may have suffered by paying Russia to fly astronauts to the ISS.

Christensen views Commercial Crew as an important first step in seeding a new economy in low Earth orbit. He thinks the resilience inherent in having multiple providers is good for the long-term well-being of U.S. space efforts.

With Starliner and Crew Dragon on the verge of test flights, the industry is looking ahead to whether private passengers will start to get in line — and whether commercial spaceflight is even viable.

◀ **The SpaceX ship that** will recover the Crew Dragon spacecraft and astronauts after splashdown has a medical treatment facility and helipad.
SpaceX

Now with Starliner and Crew Dragon on the verge of test flights, the industry is looking ahead to whether private passengers will start to get in line.

Success of Commercial Crew won't be just in the technological sense, but instead "in the business sense of who can sell their product in the marketplace," says Wayne Hale, a former space shuttle program manager and now a consultant on human rating for Boeing and United Launch Alliance.

Also a member of the NASA Advisory Council, Hale thinks it's "very likely" tourists will want to pay visits to the space station and that those may be internationally negotiable. He figures both the Starliner and Crew Dragon could go anywhere in low Earth orbit.

NASA's Jurczyk predicts astronauts from other countries' space programs will be the first to buy seats on a Crew Dragon or a Starliner but hopes the companies will also try to generate demand among the likes of Axiom Space, which has plans for a commercial space station, and Bigelow Aerospace, which plans to open a hotel.

Hale thinks SpaceX and Boeing have a shot at selling tickets and that right now, on the cusp of the first Commercial Crew test flights, the world could be about to witness a boom in space travel. He thinks the privileged few could swell by ten- to a hundredfold in a decade.

Tommy Sanford, executive director of the Commercial Spaceflight Federation, compares the anticipated eclectic mix of private passengers with the first travelers to cross North America by railroad. They went to work in manufacturing, materials science, health and agriculture — the same kinds of things that will soon be done in orbit.

"One of the biggest barriers that researchers talk about is not having folks [in space] who are researchers and scientists working with the capability hands-on," Sanford says. "Who knows what are all the benefits that are bound to be gained from that?" ★

RE-ENGINING A LE

GEND

The U.S. Air Force's strategy for ensuring the nuclear deterrence and conventional firepower of its bomber forces through the 2050s and beyond will require installing commercial jet engines onto its B-52s. Jan Tegler spoke to the Air Force and industry managers who must pull off this re-engining on time and on budget.

BY JAN TEGLER | wingsorb@aol.com

U.S. airmen work on a B-52 Stratofortress engine at Barksdale Air Force Base, La.
U.S. Air Force

Dennis Thibodeau, a retired Pratt & Whitney engine assembly line technician, knows as well as anyone the lengths that the U.S. Air Force has gone over the decades to keep its iconic B-52 bombers flying in their strategic bombing and deterrence roles. Visiting the famous aircraft boneyard at Davis-Monthan Air Force Base in Arizona in 2004, Thibodeau recalls seeing Lockheed C-141 Starlifter transport aircraft being scrapped.

"They were cutting the 141s' fuselages up but the Air Force officer escorting us told us the engines were being saved" for overhaul as spares for the B-52 fleet, he says.

Thibodeau had done his part three decades earlier as a U.S. Air Force B-52 crew chief in Thailand to keep the planes flying over Vietnam. After joining Pratt in 1974, Thibodeau went on to help assemble many of the TF33 turbofan engines that continue to power B-52s today but can't much longer, largely because of the cost and difficulty of finding replacement parts.

In fact, the Air Force now estimates that by 2030 the engines will be "unsustainable."

That timing is a problem, because the Air Force announced last February in its 2019 budget request that it plans to continue flying B-52s "through 2050-plus," because of their favorable operating costs and utility compared to the newer B-1Bs and B-2s.

A sizeable portion of the U.S. nuclear deterrence and conventional bombing capabilities, therefore, will be riding on a re-engining program that will begin unfolding this year with selection of a company or companies to supply engines under a program called CERP, short for Commercial Engine Replacement Program, the word commercial referring to engines of a kind that also power commercial jets.

The re-engining program must roll out smoothly despite lofty fuel efficiency and militarization goals. By the mid 2030s, the Air Force plans to fly just two kinds of bombers for conventional and nuclear-deterrence missions: The Big Ugly Fat F - - - -r, or BUFFs, as the B-52s are known, and a planned fleet of 100 sleek B-21 Raiders, the Northrop Grumman-manufactured stealth bombers.

"The bomber fleet is bifurcating between a penetrator and a bomb truck," explains Richard Aboulafia, a military aviation analyst for the Teal Group in Virginia. "With a penetrator, if you have maybe 100 B-21s, then the B-2s look not as good and more expensive to operate, and the B-1 has always been an expensive problem child."

The re-engine winner or winners must improve fuel efficiency by 20 to 40 percent without sacrificing performance; cope with the B-52's unusual design of two engines on each of four wing struts; and conquer an array of electrical and aerodynamic challenges. There is little margin for delay, with the B-1s and B-2s poised for retirement by the mid 2030s.

The 2019 National Defense Authorization Act (signed by President Trump in August) provides funding for CERP for the period of the current Future Years Defense Program, meaning through 2023, says Air Force Lt. Col. Gavin Berne, Global Strike Command's deputy chief of bomber requirements.

"IF YOU WANT TO SUSTAIN THE BASIC TF33 THROUGH 2030 OR 2040, WE CERTAINLY CAN DO THAT." KEEPING THE PLANES "VIABLE BEYOND 2050, THAT'S A DIFFERENT CHALLENGE."

— Mike Moeller, Pratt & Whitney

The time has come

The idea of switching B-52 bombers to a new kind of engine has been around nearly as long as the Air Force has been flying the famed aircraft.

"The oldest suggestion of a potential re-engine for the B-52 that I've seen was from 1969," says James Kroening, Boeing's B-52 program manager.

That's not that long after U.S. Strategic Air Command began flying the B-52B in 1955, carrying nuclear bombs to deter the Soviet Union. Now, after starring roles in the Cold War, the Vietnam War, the Persian Gulf War and the wars in Afghanistan and Iraq, equipping the B-52 fleet with new engines is a $1.56 billion idea whose time has finally come.

At least four formal proposals to re-engine the bomber and more than twice as many studies on the subject date back to the 1970s. Better fuel efficiency, lower maintenance costs and diminished need for aerial refueling were cited as economic and operational benefits. But each proposal failed, primarily because the Air Force always believed the B-52 would be replaced by newer bombers, including the B-1 and B-2. The potential life of the B-52 was "perceived to be much shorter than 2050," Kroening notes. "So the business case didn't result in the same economic benefit they might realize now."

Pratt & Whitney stopped building the TF33 engines in 1984. The first TF33s entered service in 1960 with 936 produced in total. Every B-52H, the version flying today, is powered by eight TF33 engines. The Air Force has kept these engines in service with the aforementioned ingenuity and by strictly adhering to routine maintenance practices buttressed by periodic overhauls at a cost of nearly $2 million per engine, according to Boeing.

The turning point came in a 2017 memo circulated by Air Force Materiel Command's Propulsion Directorate. The memo stated that the TF33 engines would be unsustainable in just over a decade. By that time, the Air Force had decided internally that it would extend the B-52's lifespan, though the announcement was still seven months away.

The memo was a "game changer," says Berne, the bomber requirements deputy. "It wasn't just about saving money anymore. It was about keeping the aircraft flying."

The Air Force's reference to flying through 2050 "plus" has contractors thinking. "If you want to sustain the basic TF33 through 2030 or 2040, we certainly can do that," says Pratt & Whitney's Mike Moeller, a former B-52 instructor pilot and retired Air Force lieutenant general. Keeping the planes "viable beyond 2050, that's a different challenge," says Moeller, the vice president for business development and integration at the company's Military Engines unit.

The Air Force views B-52s as more versatile than B-1Bs or B-2s, because each can carry a wide range of conventional munitions as well as the nuclear-capable Long Range Standoff cruise missile that could debut in 2030. Plus, B-52s are cheaper to fly and require fewer maintenance man hours than the 1970s-designed B-1B and 1980s-designed B-2. The Air Force also suspects that the stealthy advantages of the B-2 will have waned by the 2030s, noting in its "Bomber Vector," as it calls the bomber plan released along with the 2019 budget request, that the B-2 "will see its technological advantages diminish in the not-too-distant future."

▼ A U.S. airman checks the eight J57 engines on a B-52 at Tinker Air Force Base, Okla., in the late 1950s. The Air Force shifted to TF33 turbofan engines for today's B-52H versions that began flying in operations in 1961.

U.S. Air Force

Bomber-bizjet fusion

"Speed and simplicity" are behind the Air Force's desire to marry commercial engines and the BUFF, says the Air Force's Jim Noetzel, a former commander of the 96th Bomb Squadron and now the requirements lead at Global Strike Command for the re-engining program. "This will not be a developmental engine," he stresses. "We looked at the benefits of refurbishing the TF33, compared that to commercial off-the-shelf engines and asked what would be the fastest, cheapest? That led to our requirement for new commercial, in-production engines."

Noetzel and Berne refer to CERP as a "modification" built upon recent and previous re-engine studies, including proposals for a four-engine configuration. Boeing and Rolls-Royce advanced a four-engine concept in 1996, proposing four RB-211 turbofans with 40,000 pounds of thrust (178 kN) apiece.

But now, Boeing, as the engine integrator for CERP, says any deviation from the B-52's eight engines arranged in twin nacelles on the four struts would necessitate a host of expensive changes to the bomber's airframe. So eight engines it is.

"Struts and nacelles will be replaced but it is our intent that the size, weight, thrust capacity, etc., of the engines are such that handling characteristics that are impacted won't be a significant actor," explains Kroening, the Boeing B-52 manager.

The Air Force hadn't released detailed requirements at the time of this writing but enough basics were in place for engine manufacturers to suggest commercial engines that might be retrofitted to the B-52. The engines they have proposed power a range of business jets and regional airliners. Some also power Air Force transport and communications aircraft.

Pratt & Whitney plans to offer its PW815 turbofan, says Moeller. Currently on the new Gulfstream G600 business jet, the engine was also selected to power General Atomics Aeronautical Systems' unsuccessful contender for the Navy's MQ-25 Stingray refueling drone.

As exciting as a win would be, Moeller cautions that Pratt & Whitney's "job one" is to sustain the

▼ U.S. airmen look for leaks from a B-52 Stratofortress' running TF33 engines. In-depth inspections like this one at Barksdale Air Force Base, La., are required after every 450 flying hours. The Air Force estimates the engines will be "unsustainable" by 2030.

U.S. Air Force

MODERNIZING THE U.S. BOMBER FLEET

AIRCRAFT	NUMBER	FLYING WHEN	MADE BY	PRODUCTION	FIRST COMBAT
B-52H	76	Through 2050s "plus"	Boeing	1961 - 1962	Vietnam, 1965
B-1B	63	To be retired by mid-2030s	Rockwell*	1984 - 1988	Iraq, 1998
B-2	20	To be retired by mid-2030s	Northrop Grumman	1987 - 2000	Kosovo, 1999
B-21	100	First planes are projected to enter service in 2025	Northrop Grumman	No one is saying yet	Unknowable

* Boeing acquired Rockwell's aerospace and defense businesses in 1996.

current TF33 fleet. "There are going to be TF33s flying deep into the 2030s. So our primary responsibility is the operational readiness of the TF33."

Craig McVay of Rolls-Royce Defense, senior vice president for military strategic systems, says his company will put forward the BR725, an engine currently flying on the Gulfstream G650. The Air Force employs the BR700 family of engines — which it calls the F130 — to power its Gulfstream C-37A transport aircraft and the Bombardier E-11 Battlefield Airborne Communications Node airborne communications relay aircraft, a military version of Bombardier's Global Express business jet.

McVay is keen to point out that United Kingdom-based Rolls-Royce Defense would assemble and test the BR725 in the U.S. if the Air Force selects it. "It will be a U.S.-made engine with a high U.S. part content."

Karl Sheldon, GE Aviation's vice president and general manager of large military engines, reports that GE plans to offer a version of its CF34 turbofan engines that power Bombardier's Challenger business jets and CRJ regional airliners, as well as Embraer's E-Jet series of regional airliners. The company will also propose its new Passport 20 turbofan, which is now entering service on Bombardier's Global 7500 business jet.

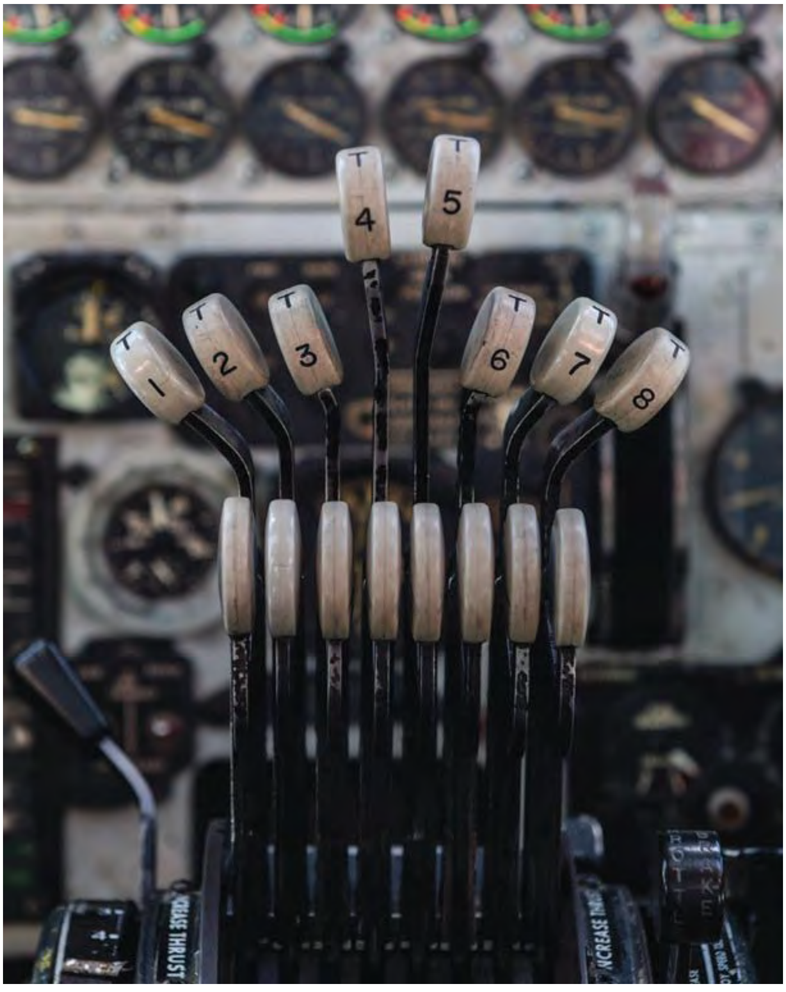
Matching commercial engines with military requirements

Noetzel says the Air Force wants candidate engines to be in the same 17,000-pound thrust (75.6 kilonewtons) class as the TF33 and produce "no change to current minimum control airspeed" of the B-52 while "maintaining the aircraft's current combat ceiling and takeoff performance."

New engines must also "be compatible with current B-52 electrical, hydraulic, pneumatic and fuel systems" and be capable of being changed quickly if necessary. External weapons carriage should be "unaffected" by the new engines and they must have a quick-start capability to allow the B-52 to "maintain its current capabilities for nuclear and operational missions," according to Berne.

Each of the engine makers told me they were confident their commercial powerplants can meet the Air Force's requirements for performance. The challenge they say is integrating their commercial engines with the B-52 and adapting them for military use.

▼ Eight throttles control the engines of a B-52.



U.S. Air Force

▲ U.S. Air Force aerospace propulsion technicians practice repairs on a trainer B-52 engine at Barksdale Air Force Base, La.

For example, military engines and control systems must be nuclear-hardened. The radiation associated with a nuclear blast can physically damage semiconductors in electronics causing a variety of aircraft systems, including engines, to malfunction. Nuclear hardening makes electronic components resistant to radiation by using different manufacturing techniques and radiation-tolerant materials in the production of semiconductors.

They must also perform in circumstances commercial engines are not designed for, including aerial refueling. There are also issues to be solved with packaging commercial engines in a form that doesn't deviate too much from the current pod configuration that houses two TF33 engines. "We've already started to do some work on our own," GE's Sheldon explains, "thinking about how the engines fit on a pod, how they would be closely coupled together, what kind of distortion tolerance we have on each fan to take in some worst-case scenario, refueling distortion, all of that in advance."

CERP will complement the work already being done to bring the analog B-52 into the digital age. This includes new combat network communications technology, a weapons bay improvement program that will enable the B-52 to carry smart weapons internally, Link-16 tactical data link capability and upgraded GPS interface units for the aircraft's computers.

Analog-to-digital transformation will be a major feature of CERP. Commercial jet engines come with electronic engine controllers. Kroening says Boeing's role as integrator will be to provide the interface between those controllers and the airframe and the cockpit, and control mechanisms in the cockpit.

U.S. Air Force

"IF YOU SAT IN THE COCKPIT OF THE B-52 TODAY, YOU WOULD SEE DIAL GAUGES THAT SHOW ENGINE INSTRUMENT STATUS. WE'LL BE REPLACING THOSE WITH LCD DISPLAYS THAT DEPICT THAT STATUS. WE'LL HAVE TO REPLACE THE THROTTLE STATION ITSELF AND CREATE THE ELECTRONICS THAT REPLACE THE PHYSICAL CABLE TYPE CONNECTION BETWEEN THE ENGINES AND THE THROTTLES."

— James Kroening, Boeing's B-52 program manager

"That's a significant part of the modification," Kroening stresses. "If you sat in the cockpit of the B-52 today, you would see dial gauges that show engine instrument status. We'll be replacing those with LCD displays that depict that status. We'll have to replace the throttle station itself and create the electronics that replace the physical cable type connection between the engines and the throttles."

The Air Force's quick-start requirement is another integration challenge. The B-52 lacks onboard starting capability. The bomber's TF33s are started in two ways currently. For normal operations the B-52 starts pneumatically. A ground crew wheels a cart-mounted auxiliary power unit, or APU, to the airplane and attaches a hose to a fitting on the inboard pod on the left wing that houses the No. 3 and No. 4 TF33s. Activating the APU, compressed air is supplied via the hose to rotate engine compressor spools. With sufficient pressurized air in the combustion chamber, fuel is introduced to the engine, ignited and the turbofan starts. Once these engines are stabilized, bleed air is sent from them to start the others. In addition, APUs supply electric and hydraulic power to the aircraft without the need to start the engines.

Alternatively, explosive cartridges can provide quick engine starts for B-52s assigned to the nuclear alert mission. Gunpowder cartridges are inserted into breaches on the engines. Firing each cartridge ignites fuel supplied to each engine and starts all eight simultaneously.

Berne says that for the nuclear mission, B-52s must be able to start without external equipment.

In addition to producing engines, Pratt & Whitney has a division that supplies a range of auxiliary power units to start the engines on commercial airliners. That gives the company an edge, Moeller says, because it can integrate an APU with the PW815 in-house to provide a quick-start method none of the competitors can offer. "We believe Pratt & Whitney is uniquely positioned because we have the ability to provide the PW815 as well as an APU solution."

That said, Boeing and Paris-based engine manufacturer Safran (a partner with GE Aviation on the CFM-56, which now powers most KC-135 tankers) entered into a partnership last November to produce APUs. It's not known if Safran will vie for CERP but if it did, it could also offer an integrated quick-start approach.

While the Air Force has touted fuel savings and lower maintenance costs of new engines, it has been less vocal about another CERP requirement: the capability of a new engine to generate significantly more electrical power than the TF33.

"If you step back and look at this re-engine program, electrical power is probably the single biggest area of improved performance that is a requirement," says Kroening, Boeing's B-52 manager.

At this writing, the engine manufacturers hadn't been told how much extra capacity the Air Force wants, but greater electric power could support a host of future improvements to the B-52, from defensive directed energy weapons systems and hypersonic weapons to new sensors and avionics.

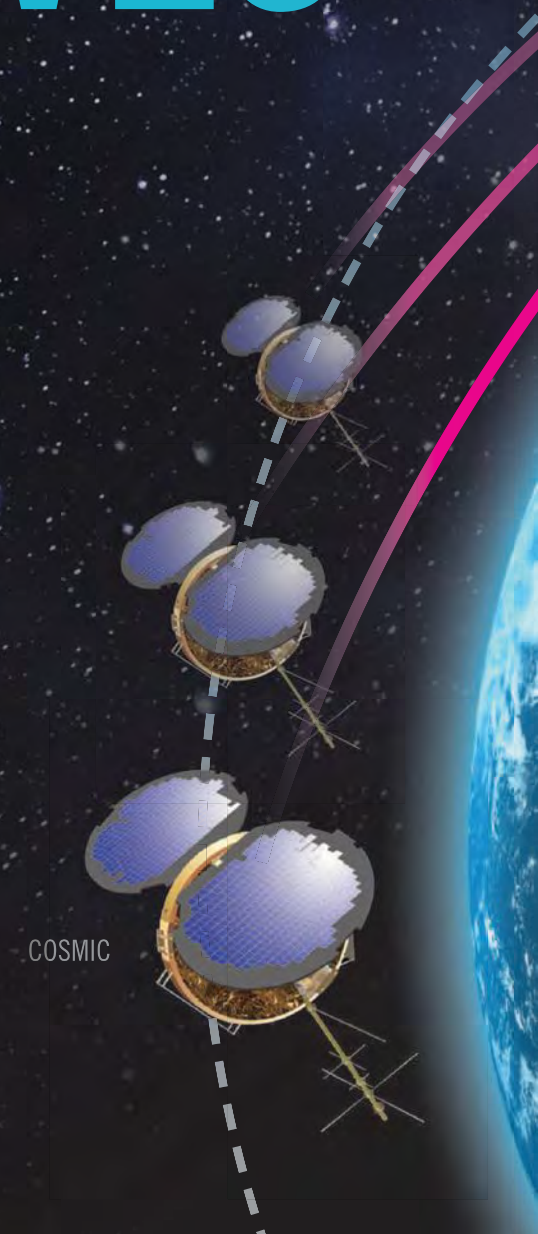
Global Strike Command's Berne says that having a modern propulsion system to keep the B-52 flying is the central element of CERP but that improved electrical power generation capability is critical for future viability.

"We don't really know what's out there that we'll be integrating with the airplane 20 or 30 years from now," he says. But we've got to start to provide the electrical power margin to take on those new systems." ★

PROVING THEMSELVES

Weather forecasters are always hungry for more data. Over the last few years, they've learned that signals from GPS and rival constellations can tell them interesting things about the atmosphere. The question is whether cubesats and other smallsats can gather these radio occultation readings accurately enough. **Debra Werner** takes the measure of a congressionally directed pilot project that could provide the answer.

BY DEBRA WERNER | werner.debra@gmail.com



COLLECTING DATA FOR WEATHER FORECASTS

Three startups have won the right to prove that radio occultation readings from their small satellites can offer accurate weather forecasting data. In this illustration, satellites in the Constellation Observing System for Meteorology, Ionosphere and Climate system, left, pick up signals from GPS satellites.

Source: NOAA

When radio waves pass through a planet's atmosphere, the molecules and electrons bend the waves not unlike how a piece of glass or body of water refracts light. The denser the atmosphere, the more bending. NASA scientists famously put this principle to work in 1965 during the Mariner 4 mission. After passing Mars, the probe transmitted radio waves back toward Earth with the red planet partially blocking, or occulting, the path. This assured that some of the radio waves passed through the Martian atmosphere. The technique, called radio occultation, gave scientists their first precise measurement of the density of the Martian atmosphere.

Flash forward five decades, and Earth is now ringed with a constellation of 24 GPS satellites, plus rival constellations operated by China, Europe and Russia. Some microwaves from these satellites plow through the atmosphere including cloud cover to reach users on the ground, but some inevitably radiate past the curve of the Earth and into space. An instrument orbiting on the other side of the globe can catch these navigation signals. From the degree of bending, software on the satellite or on the ground can deduce moisture content, air pressure and temperatures at various altitudes, with each set of data called a sounding.

Scientists have long been intrigued by this technique, called radio occultation, but as recently as a decade ago, they were unsure of its precision in the lower atmosphere.

Radio occultation: How it works

Sensors mounted on satellites travelling in low Earth orbit continually observe radio signals broadcast by global navigation satellites in medium Earth orbit. For example, satellites in the Constellation Observing System for Meteorology, Ionosphere and Climate, launched in 2006 by NOAA and Taiwan's National Space Organization, orbiting 800 kilometers overhead acquired signals from GPS satellites in 20,200-kilometer orbits.

Each COSMIC satellite observed a GPS signal for about three minutes or one occultation before the spacecraft passed behind Earth where it could no longer see the GPS spacecraft. Software on the satellites and in ground stations measures how the atmosphere refracts GPS signals, providing precise observations known as soundings that reveal atmospheric temperature, pressure, density and water vapor in an atmospheric column.

A turning point came after Typhoon Nuri struck the Philippines in 2008, explains meteorologist William Kuo of the University Corporation for Atmospheric Research, a Boulder, Colorado, nonprofit focused on research and training forecasters and young scientists. The storm originated in an area of the Western Pacific Ocean that was shrouded in clouds that blocked the view of the lower troposphere for weather satellites that rely on traditional microwave soundings to chart temperatures by measuring microwave energy emitted from the atmosphere and surface. Weather balloons, in theory, could have given clues about what was happening under the clouds, but the Pacific Ocean is vast and no balloons were in the area. U.S. and European weather models did not capture the moisture under the clouds and failed to predict the formation of Nuri, which exploded into one of the year's strongest cyclones.

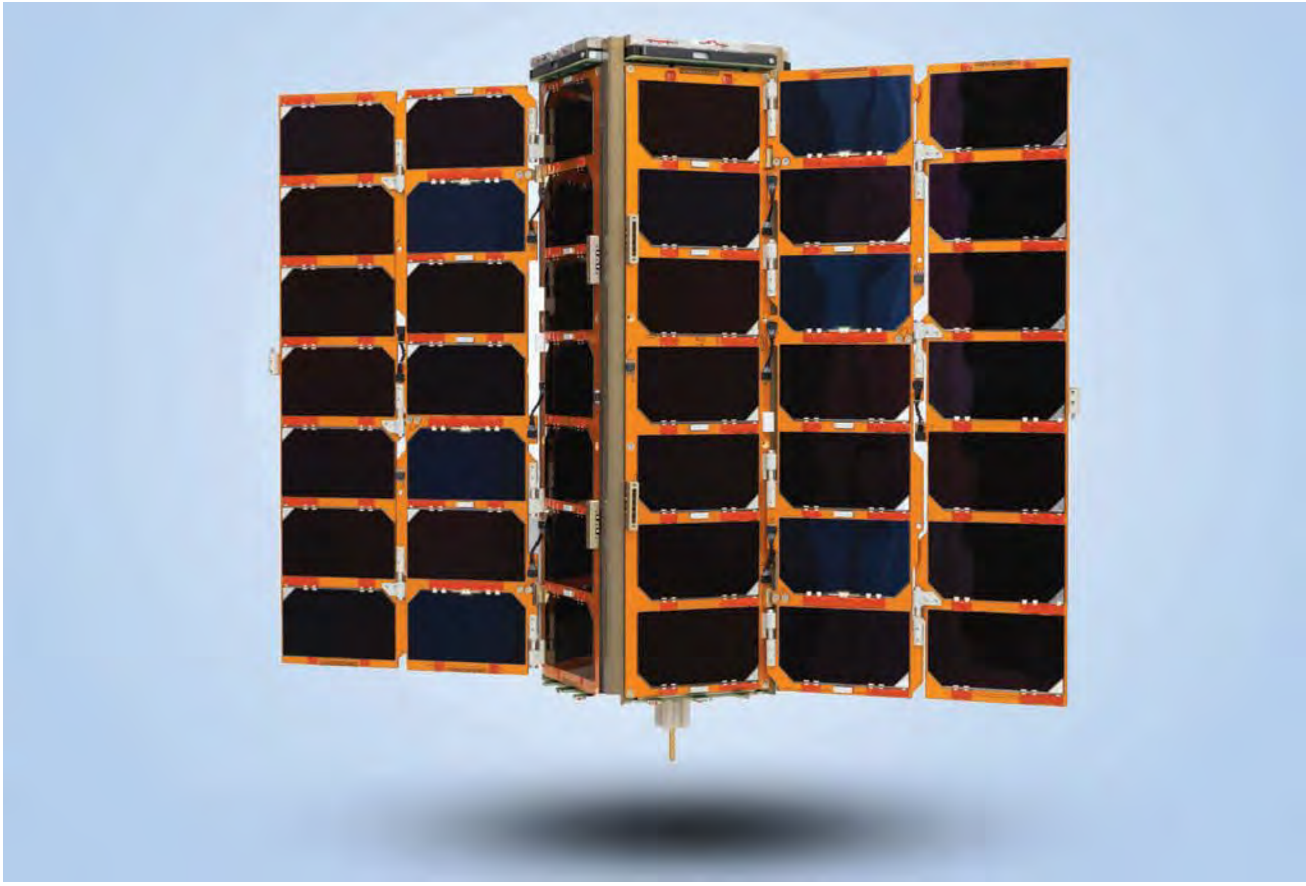
After Nuri, researchers led by Kuo were curious to see whether radio occultation could have shown the models what lay under the clouds. They acquired archived radio occultation readings of that area of the Pacific taken during Nuri's formation by a constellation of NOAA and Taiwan-funded technology demonstration satellites called COSMIC, for Constellation Observing System for Meteorology, Ionosphere and Climate, and other satellites. Kuo and his team discovered that by adding radio occultation measurements from GPS into the forecast model, they could see spiral rainbands associated with the developing storm. The model was now able to predict Typhoon Nuri.

The Nuri study, often presented by scientists at conferences with a video of the decloaked rotation, helped NOAA and Taiwan's National Space Organization win funding in 2010 and 2011 for a second generation of COSMIC satellites.

Small-sat entrepreneurs jump in

Now, entrepreneurs in the U.S., aided by a NOAA-managed pilot project, are racing to bring radio occultation to market and do it with smallsats and cubesats that are just a fraction the size of the COSMIC satellites. Despite early setbacks, these entrepreneurs retain an unshakeable conviction that the technique can revolutionize forecasting and earn them a sizeable share of what could be a multibillion-dollar global market for various kinds of commercial weather data, including radio occultation soundings.

NOAA, on orders of Congress, is doing what it can to nurture the industry through the 2-year-old Commercial Weather Data Pilot project. In September, NOAA awarded a total of $8.3 million in second-round contracts to three weather satellite startups: GeoOptics of Pasadena, California; PlanetiQ of


Spire Global

▲ **Spire Global was the** first startup to operate a constellation of radio occultation cubesats.

Golden, Colorado; and San Francisco-based Spire Global. Their occultation readings will be fed into offline forecasting models so that results can be compared to those from operational models.

NOAA is hoping for better results this time than from the first round of the pilot in April 2017, when the agency did not receive enough soundings to assess the technology. GeoOptics, which received $695,000 in the first round, didn't launch any satellites in time to meet the deadline. Spire, which received $370,000, provided some observations but not enough for a full assessment. NOAA decided to add PlanetiQ for the second round.

"We saw enough promise coming out of the first round that we knew it was worth at least doing round two," says NOAA's Karen St. Germain, a microwave remote sensing expert. "I am optimistic about it. They are probably going to get to a good capability that can be a part of the overall NOAA observation portfolio moving forward," St. Germain adds. She directs the Office of Systems Architecture and Advanced Planning within NOAA's National Environmental Satellite, Data and Information Service, the agency that feeds observations from satellites and weather balloons into supercomputers running forecast models that the agency shares with meteorologists.

Watching all this closely are U.S. forecasters who are hungry for more and more occultation soundings, provided the accuracy of the data can be verified in part with the aid of COSMIC. In terms of forecasting value, the soundings from COSMIC have been "right up there with satellite infrared and microwave soundings, radiosondes and aircraft reports," says Joseph Pica, director of the National Weather Service Office of Observations.

Fine-tuning multiday forecasts

Forecasters evaluated numerical weather models with and without COSMIC data and found the additional temperature and moisture data had the largest impact on multiday forecasts, providing the quality of a four-day forecast eight hours in advance and a seven-day forecast 15 hours earlier, says Lidia Cucurull, an atmospheric physicist and deputy director of NOAA's Quantitative Observing System Assessment Program.

At its height, the COSMIC constellation produced 1,500 to 2,000 atmospheric soundings per day. Each sounding reveals pressure, temperature and humidity in an atmospheric column. Now, only one of the six COSMIC satellites works at all and it operates intermittently, which is why NOAA is preparing to launch a second COSMIC constellation.

If meteorologists had 100,000 radio occultation soundings, that "would double forecast accuracy," predicts Peter Platzer, chief executive of Spire Global, which in 2015 became the first startup to operate a constellation of radio occultation cubesats.

While that degree remains to be shown, the forecasters I interviewed agreed that a higher number of soundings would improve forecasts dramatically, particularly in the Southern Hemisphere and over the oceans, areas that don't receive as much attention from geostationary weather satellites or weather balloons.

NOAA will gauge the accuracy of the commercial observations gathered under the pilot project, while the Joint Center for Satellite Data Assimilation, a research agency serving NASA, NOAA and the U.S. Defense Department, will assess their impact on forecasts.

"Different vendors may well deliver occultation observations that have different performance characteristics," says St. Germain. "We want to understand the value they can provide."

Much of St. Germain's optimism can be traced to COSMIC. In 2011, the European Center for Medium-Range Weather Forecasts studied the value of various weather model inputs by removing specific datasets and gauging the impact on forecasts. When researchers compared forecasts with and without radio occultation, they found that the additional observations reduced forecast error by 10 percent. That impact reportedly impressed them, because radio occultation satellites provide only 2 to 3 percent of the observations fed into the forecast models.

A similar 2010 study by NOAA's National Center for Environmental Prediction revealed radio occultation had the third highest impact per observation on a NASA Goddard Earth Observing Systems weather model behind radiosondes and ship buoys.

Pointing to that evidence, NOAA won congressional support for the second COSMIC constellation. COSMIC-2, a six-satellite constellation scheduled to launch into an equatorial orbit on a SpaceX Falcon Heavy rocket in 2019, possibly as early as April or May, will feed data directly into numerical weather models. If all goes according to plan, six COSMIC-2 satellites will capture a total of 5,000 soundings per day between 40 degrees north and 40 degrees south latitude, where much of Earth's population lives. Those observations will be fed into forecast models within 30 minutes.

Within that coverage area, COSMIC-2 is focused on the tropics because that's where the atmosphere holds most of its moisture and moisture "drives the global weather engine," says Bill Schreiner, the COSMIC project director for the University Corporation for Atmospheric Research in Colorado.

COSMIC-2 is a paired-down version of the constellation that was originally conceived in 2010. At that time, managers envisioned following the first tranche of six satellites orbiting over the equator with a second six-satellite constellation, dubbed COSMIC-2B, with the satellites crossing from pole to pole. The United States and Taiwan canceled plans in 2017 to build those satellites, because neither government was willing to fund them.

NOAA Commercial Weather Data Pilot

NOAA awarded contracts in September to three small businesses to provide radio occultation observations. This was the second round of the agency's Commercial Weather Data Pilot, an initiative to explore how various types of commercial Earth observations could be fed into NOAA meteorological models.

The agency awarded $3.4 million to GeoOptics Inc. of Pasadena, California; $3.5 million to PlanetiQ of Boulder, Colorado; and $1.4 million to Spire Global of San Francisco to deliver radio occultation soundings by July 31, 2019. NOAA is scheduled to assess the data and report its findings in mid-2020.

Congress pushes for commercial sources

By the time COSMIC-2B was canceled, entrepreneurs were designing and building radio occultation cubesats and, in Spire's case, operating them. The trend toward miniature electronics means companies can fit radio occultation receivers and powerful processers into satellites of 5 to 18 kilograms compared to the original COSMICs, each of which weighed about 70 kilograms. The new COSMICs will be even larger, at close to 300 kilograms, because each will carry redundant electronic components and extra scientific payloads. Congress, seeing progress on the commercial side, pushed NOAA to compare the cost and capability of commercial constellations with government satellites.

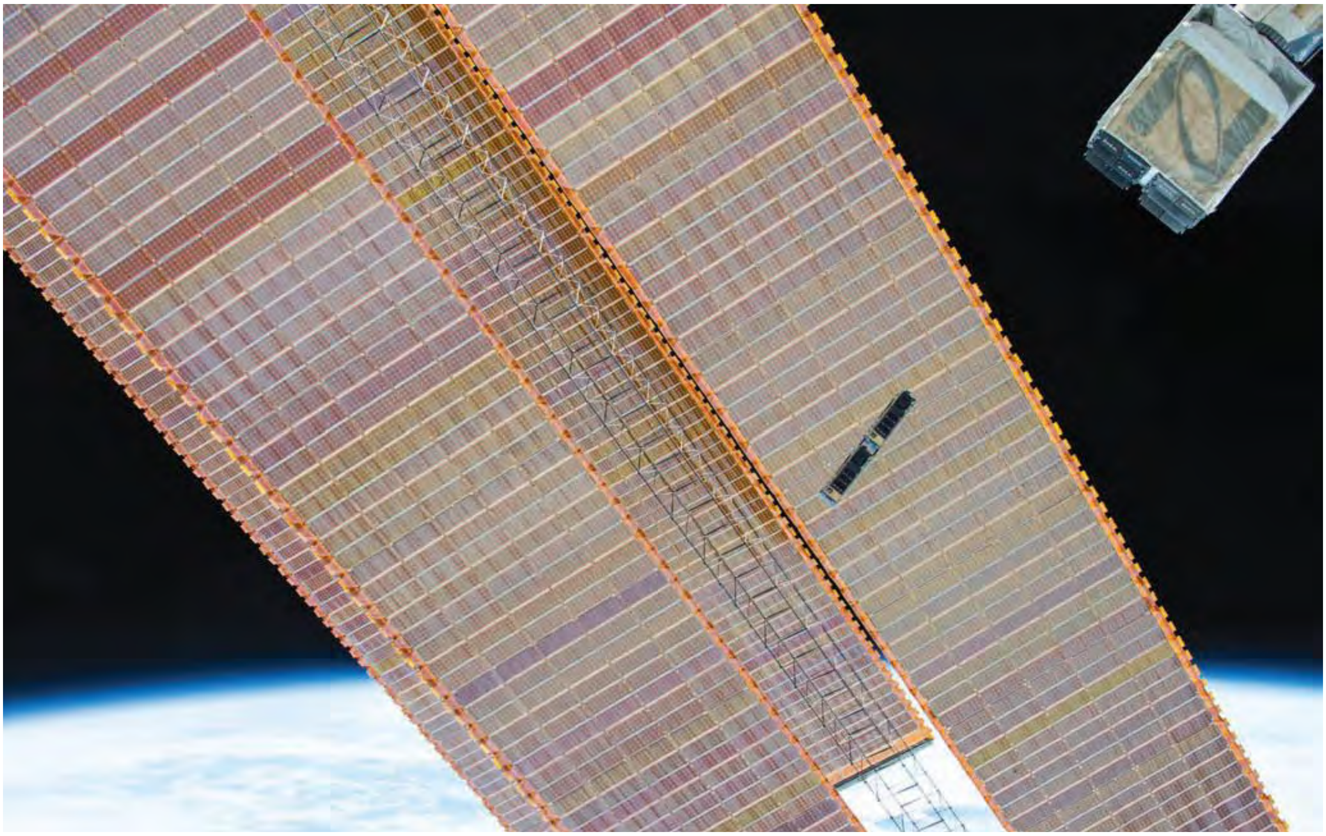
In a report accompanying a 2017 appropriations bill, Congress asked NOAA to provide a detailed comparison of the cost of acquiring radio occultation data from the COSMIC-2's polar-orbiting constellation, including development, launch and operations, with commercial data sources, a comparison that led to the demise of COSMIC-2B.

Schreiner, the project director at the University Corporation for Atmsopheric Research, was sorry to lose COSMIC-2B. "It would have allowed us to provide excellent improvements to weather forecasting and to monitor the quality of commercial systems," he says. "There is plenty of room for commercial data. Studies show significant impact from radio occultation even when you have 100,000 soundings per day."

Entrepreneurs, on the other hand, were pleased Congress pushed NOAA to support their fledgling ventures. Jim Bridenstine, the Oklahoma Republican who was a member of the House of Representative's Space, Science and Technology Committee before becoming NASA administrator last year, led the congressional campaign for commercial radio occultation.

Bridenstine found ready allies in the industry. "There's no question you get more for your money with a commercial service," says retired U.S. Navy Adm. Conrad Lautenbacher, a former NOAA administrator who now leads GeoOptics. "Federal government funding is essential for research, but the commercial sector is the most cost-effective provider of proven products and services."

▼ **GeoOptics operates Cicero radio** occultation cubesats with sensors it developed with the NASA-funded Jet Propulsion Laboratory and Tyvak Nano-Satellite Systems, a small spacecraft builder in Irvine, Calif.
GeoOptics



NASA

▲ **Spire Global cubesats** are pushed out of the International Space Station by the NanoRacks Cubesat Deployer.

As of Dec. 5, Lautenbacher's company was operating three 10-kilogram Cicero radio occultation cubesats with sensors it developed with the NASA-funded Jet Propulsion Laboratory and Tyvak Nano-Satellite Systems, a small spacecraft builder in Irvine, California.

GeoOptics' shoebox-size satellites "produce data that compares very favorably with COSMIC-1 data," Lautenbacher says.

Spire, meanwhile, operates a fleet of about 71 5-kilogram cubesats that it calls Lemurs. Each is equipped with radio occultation sensors in addition to Automatic Identification System receivers for maritime tracking. Spire also began installing Automatic Dependent Surveillance-Broadcast receivers for airplane tracking in its new cubesats in 2018.

"Our three-unit cubesats, the size of a wine bottle, track the weather, ships, planes and a whole bunch of other things," Spire's Platzer says. "They have higher-gain antennas than COSMIC-1 and two to three orders of magnitude more processing power."

PlanetiQ has built three radio occultation satellites but not yet launched one. If all goes according to plan, PlanetiQ's 12-unit cubesats, built to track radio signals from GPS as well as Russian GLONASS, European Galileo and Chinese BeiDou navigation satellites, will begin launching in 2019.

"We'll get three up toward the end of the year on three different launchers," says Chris McCormick, PlanetiQ founder and chairman.

McCormick, who led Broad Reach Engineering when it built radio occultation receivers for COSMIC-1, Germany's radar satellite TerraSAR-X and TanDEM-X, and others , is confident PlanetiQ's commercial receivers will outperform COSMIC-1's.

COSMIC-1 receivers were built in 2004, meaning the technology was selected around 2002.

"Sixteen years later, a lot of other things are better from an instrument perspective," McCormick says. "Our antennas are actually bigger than COSMIC-1 antennas. We'll have better signal-to-noise ratio, faster computers and we'll be tracking most of the Global Navigation Satellite System signals not just GPS."

The most striking difference between commercial radio occultation satellites and their government flown counterparts is the volume of precise, geographically dispersed observations they could potentially provide for weather and climate models. McCormick compares it to adding pixels to improve the resolution of an image. Worldwide, agencies launch 1,800 weather balloons, measuring temperature, pressure and humidity in an air column. In contrast, one PlanetiQ satellite will gather 2,500 soundings per day.

"We'll get more soundings with one satellite than all the weather balloons and we are going to be launching 18 satellites," McCormick says. That, says McCormick, is what's needed to improve the precision and accuracy of forecasts. ★

Gusts of change

The world appears to be on the cusp of an explosion in personal and passenger air travel and commercial exploitation of space. It's exciting, but the environmental and societal concerns of the coming revolution need to be considered starting now. Aerospace expert Amir S. Gohardani explains.

BY AMIR S. GOHARDANI

Dynamic gusts of change are the hallmark of the 21st century. Limited natural resources on Earth and an increase in global population make access to space and debates about ongoing air and space activities more relevant than ever. The solution to many looming environmental and societal challenges created by the aerospace sector lies in collaboration among those in different disciplines in addition to the identification of synergistic benefits between domains, such as artificial intelligence and aircraft flight control.

Here is the scope of the challenge: The World Bank projects the planet's population to grow from 7.5 billion in 2018 to 11.2 billion in 2100, with over 80 percent of the world living in either Africa or Asia. If a large percentage of these communities receive packages via drones, fly to work every day, and fly halfway around the world, the environmental impacts of these developments would be enormous.

Technical advances have always posed environmental and societal tradeoffs. Consider the creation of the telegraph as described by historian Tom Standage in his book "The Victorian Internet." In the 1850s, Paul Julius Reuter, the founder of the Reuters News Agency, delivered news and stock prices to customers via a combination of telegraph cables and carrier pigeons. Determined to offer timely information between Aachen and Brussels, Reuter increased the number of carrier pigeons — exceeding 200 pigeons — in pace with increasing demand. He operated this service for a year until a gap in the telegraph link was finally closed. The future of aerospace technologies bares many resemblances to this historical case.

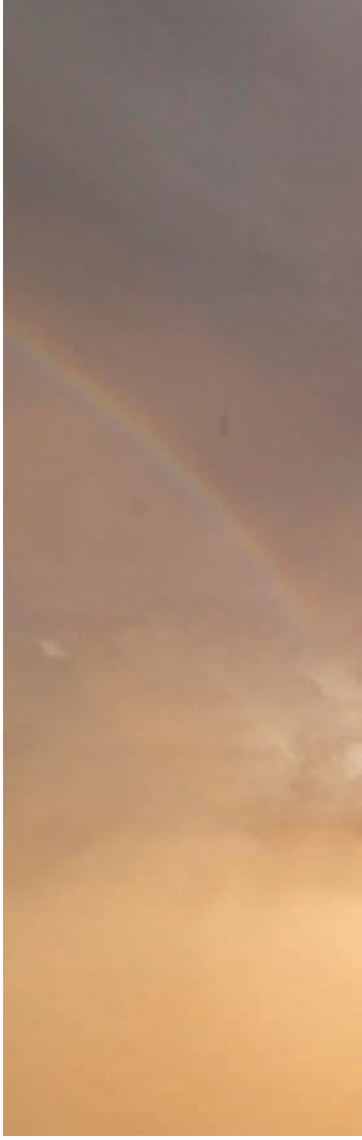
Swarm of drones

For the aerospace industry, a near-term opportunity and challenge is the advent of drone technologies in our everyday lives. The massive explosion of drones in the consumer market and the operational history of larger drones such as the Predator within the U.S. military and defense sector, showcase how a specific technology can affect society. Two decades ago, pipeline monitoring had to be carried out by a specially designed aerial platform or a military drone whereas today it is possible to use an off-the-shelf quadrotor equipped with a camera and achieve the same objective. The ongoing drone trends raise a legitimate question: Does technology, policy, or society fuel the drone trends?

In a throwback to Reuter's carrier pigeon solution, one can answer this question in several ways. The short answer is, naturally, that it all depends. Initially, it appears as if these trends are simply driven by supply and demand. In recent years, the toy market identified the demand for toy drones and this resulted in a favorable marketplace for these products based on the colossal consumer demand. Similarly, the use of pigeons as a replacement for the telegraph was a short-term solution propelled by the demand for information. In absence of any pre-existing policy bans, a timely policy was adopted for using pigeons as information carriers. In the case of future aerial drones, unless other robust and efficient technologies would be available in the marketplace to challenge aerial drones, it would be difficult to imagine that drone package deliveries would not be adopted, particularly if safe deliveries are made and smooth and noncongested transportation routes are rigorously established. In February 2018, a study published in Nature Communications and led by researchers at Lawrence Livermore National Laboratory and Carnegie Mellon University found that using relatively small quad- or octocopters (compared with larger military drones, for example) instead of diesel-burning delivery trucks could mean a reduction in both energy consumption and releases of greenhouse gases that contribute to climate change.

Nonetheless, policy crafting and adoption are truly convoluted processes. In case of unmanned aerial systems, policy crafting is likely to enter the scene if drone technologies and the demands of society were to invade public privacy or unfavorably disrupt the societal norms through, for instance, unethical approaches, or mishaps. Contemplate, for instance, scenarios in which a large number of drones accidentally or deliberately overload and interfere with the adopted policies in the developing UAS traffic management systems. A version of this scenario unfolded in the United Kingdom late last year. According to news reports, between Dec. 19 and 21, hundreds of flights were canceled and the runway was closed at Gatwick Airport, due to drone sightings. This incident caused major travel disruption, affecting about 140,000 passengers and over 1,000 flights. On Dec. 21, 2018, Sussex police arrested two suspects, who were released without charge on Dec. 23, 2018. Thus, through this incident, the unfortunate vulnerability of air travel was exposed with only a limited number of drones operating in the skies. Consequently, concerns about undesirable scenarios affecting societal safety and security are legitimate considerations given the increasing number of aerial platforms.

As partially alluded to earlier, policies need to take public privacy into consideration and account for the possibility of misuse and illicit activities. This is rather similar to the case with Reuter's carrier pigeons if one imagines a fictitious scenario in which a large invasion of pigeons would cause disruptions to the normal procedures and the flow of life in either Aachen or Brussels. Surely, such interruptions would not remain without any consequences. Likewise, drone technologies are considered beneficial or detrimental based on their impact. In short, if drone utilization does not paralyze societies or invoke privacy or safety concerns as in the case of Gatwick Airport, they could potentially prove to



National Research Council of Canada

SpaceX

▲ **A SpaceX Falcon 9** booster lands back in Florida after launching Es'hail-2, a communications satellite owned by Qatar Satellite Co.

◀ **A NASA HU-25C** Guardian aircraft flies behind NASA's DC-8 aircraft before it descends into the DC-8's exhaust plumes to sample ice particles and engine emissions.

be advantageous. Nonetheless, it should also be noted that drone deliveries made to urban areas might invoke a different set of privacy concerns than those considered for remote areas. Through this hypothetical exercise, it is readily evident that drone use is not explicitly confined or driven by the technology sector. In effect, regardless of the concerns about drone use and whether or not they are related to noise, line-of-sight issues, or any other factors, from a holistic perspective, the intersections among technology, policy and society dictate the final impact of drone utilization in our future societies.

Green aerial and space transportation

Originally, throughout the technical evolution of air and space transportation systems, the environmental impacts of these vehicles were viewed secondary to their enabling technologies. Following the decision to phase out lead as an ingredient of automotive gasoline in the early 1970s, aviation fuel became the largest source of lead emissions in the United States. Today, the majority of commercial aircraft do not burn leaded fuel, but piston-engine planes continue to burn the leaded aviation fuel (nicknamed avgas). According to scientists at the U.S. Department of Health and Human Services' National Toxicology program, lead and lead compounds are reasonably anticipated to be human carcinogens. EPA further estimates that 16 million people live close to one of 22,000 airports where leaded avgas is used, and about 3 million children go to schools near these airports. Even though it has been established that lead is extremely toxic to humans, wildlife and the environment, and causes health problems even at low doses, there are no plans to ban leaded aviation fuel in the U.S. In 2018, the FAA temporarily suspended flight testing and certain engine trials of the two drop-in unleaded fuel options. These were under evaluation to replace leaded aviation gasoline through the Piston Aviation Fuels Initiative. The suspension resulted in a delay in testing completion from December 2018 to mid-2020.

The impact of aviation on the environment has always been an interest of NASA. Thus, it is not merely coincidental that NASA has pursued initiatives such as the ERA, for Environmentally Responsible Aviation, project. Some of the goals were to enable reduced fuel burn, emissions and noise for futuristic air vehicles. These goals have independently been pursued by the aviation industry for decades and

NASA

▲ **NASA's DC-8 research** aircraft leads an aircraft collecting exhaust samples.

partially motivated additional measures to electrify air vehicles into hybrid electric aircraft, more electric aircraft, and all-electric aircraft concepts. Following the ERA project, aircraft designers are looking at more sustainable options to fly aircraft from point A to point B. Some of these options include changing the airframe to a blended wing body or hybrid body concepts, using alternative fuels such as biofuels and designing new aircraft power management and distribution architectures.

Environmental effects could have a larger impact in the future. According to FAA's Aerospace Forecast report for fiscal years 2018-2038, the number of aircraft in the U.S. commercial fleet is predicted to increase from 7,141 in 2017 to 8,290 in 2038, an average annual growth rate of 0.7 percent. Increased demand for air travel and growth in air cargo are expected to bring increases in the passenger and cargo fleets. With an increase of aerial transportation around the globe, the ability to sustain such growth is likely to be influenced by environmental constraints. For instance, if there are no alternative aircraft fuel options available and the aviation industry were to encounter a fossil fuel shortage, the industry would fail to meet the mobility demands and its projected annual growth rate. Yet, the switch to more sustainable aviation is unlikely to gain momentum in the absence of business incentives or measures by global bodies targeting aircraft emission reductions. In 2016, the International Civil Aviation Organization agreed on a resolution for a global market-based measure that would reduce CO_2 emissions from international aviation as of 2021. The Carbon Offsetting and Reduction Scheme for International Aviation, or CORSIA, aims to stabilize CO_2 emissions at 2020 levels by asking airlines to offset the growth of their emissions after 2020. Moreover, inefficient utilization of infrastructures that do not support new flight routes from remote areas will contribute to additional hurdles related to airport and air traffic congestion.

Environmental concerns for space activities are equally as important as those for the aviation sector. Reusable rockets and calls for daily space travel mark a technical evolution and vision for future space transportation. In an analogy to the switch from pigeons to the telegraph, reusable rockets lead to a greener approach in comparison to nonreusable rockets. In Reuter's service, mortal pigeons were replaced with a virtually immortal telegraph system that did not depend on the lifespan of living creatures. Hence, the reusability of rockets is analogous with that of the telegraph system.

In line with an anticipated increase of space transportation activities and efforts to minimize environmental impact, green space propellants are already being investigated as replacements for hydrazine rocket fuel, a highly toxic and carcinogenic chemical. If the policy adoption framework expands beyond the sole use of chemical propulsion in space, then electric space propulsion or a combination of chemical space propulsion and electric space propulsion for several space missions has already been suggested. Just as in air transportation, weight is a big concern for spacecraft. The fact that space electric propulsion provides a much higher specific impulse means the requirements call for less propellant — in comparison to chemical propulsion — and contributing to an overall lighter spacecraft. Hence, the option for a more sustainable solution utilizing electric space propulsion is available if it is in line with the overall mission objectives and in case the intended propellants are environmentally unfriendly. On the flip side, because an electric space propulsion device provides lower thrust, it must run for a longer period to produce the desired change in trajectory or velocity. Therefore, it could be ideal for a deep-space probe. Human presence in orbit contributes to additional design constraints and new calls for a thorough understanding of a radiation environment that affects human health.

A connected world

Reuter's past ambitions to share information resonates with the Information Age in which many aspire for global connectivity. One of the key objectives of the planned satellite constellations in orbit is to enable an unprecedented capability of reaching remote areas of the globe for communication purposes. Global connectivity could prove to be beneficial for humanity's progress in a world with consistent population growth. However, there is a dormant risk to space sustainability. In the case of cubesats, for instance, they have indeed proved to be beneficial for scientific and educational purposes. Be that as it may, there is a risk that technical glitches and inadequate oversight of operation of cubesats and other satellite constellations could contribute to the theoretical Kessler syndrome in which the density of objects in low Earth orbit is high enough that collisions could cause a cascade in which orbital debris increases the likelihood of further collisions. Therefore, the orbital debris threat is imminent and undoubtedly remains a likely disruption to many current and future space activities. With many ambiguities revolving around orbital debris and policy, legal uncertainties that pour into national defense and international concerns, a solution inspired by the fusion between policy and technology would be optimal for minimizing the threat of orbital debris and enabling sustainable space architectures for a connected world.

The global community would indeed greatly benefit from a sustainable environment in which many space and aerial activities could take place without major disruptions and disasters. Communication across a number of multidisciplinary subject areas and a thorough understanding of how technology interacts with society and policy is a future requirement for such endeavors. ★

Amir S. Gohardani is an AIAA associate fellow and the chair of the institute's Society and Aerospace Technology Integration and Outreach Committee. He is president of the nonprofit educational organization Springs of Dreams Corp.

AIAA Bulletin

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Other Important Numbers: Aerospace America / Karen Small, ext. 7569 • AIAA Bulletin / Christine Williams, ext. 7575 • AIAA Foundation / Merrie Scott, ext. 7530 • Book Sales / 800.682.AIAA or 703.661.1595, Dept. 415 • Communications / John Blacksten, ext. 7532 • Continuing Education / Jason Cole, ext. 7596 • Corporate Members / Tobey Jackson, ext. 7570 • Editorial, Books and Journals / Heather Brennan, ext. 7568 • Exhibits and Sponsorship / Chris Semon, ext. 7510 • Honors and Awards / Patricia Carr, ext. 7523 • Journal Subscriptions, Member / 800.639.AIAA • Journal Subscriptions, Institutional / Online Archive Subscriptions / Michele Dominiak, ext. 7531 • Media Relations / John Blacksten, ext. 7532 • Public Policy / Steve Sidorek, ext. 7541 • Section Activities / Emily Springer, ext. 7533 • Standards, Domestic / Hilary Woehrle, ext. 7546 • Standards, International / Nick Tongson, ext. 7515 • Student Programs / Rachel Dowdy, ext. 7577 • Technical Committees / Karen Berry, ext. 7537

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

Calendar

FEATURED EVENT

7–9 MAY 2019

Laurel, MD

The 2019 forum will use the 2018 National Defense Strategy as a framework to discuss the strategic, programmatic, and technical topics and policy issues pertaining to the aerospace and defense community. This Secret/NoForn event provides a venue for leaders from government, military, industry and academia to explore aerospace technologies and their application to complex national security challenges.

defense.aiaa.org

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2019			
7 Feb	Introduction to Launch Vehicle Pogo Stability	Virtual (aiaa.org/onlinelearning)	
2–9 Mar*	2019 IEEE Aerospace Conference	Big Sky, MT (www.aeroconf.org)	
20 Mar	AIAA Congressional Visits Day (CVD)	Washington, DC (aiaa.org/CVD)	
25–27 Mar*	54th 3AF International Conference on Applied Aerodynamics	Paris, France (http://3af-aerodynamics2019.com)	
29–31 Mar	Region IV Student Conference (University of Texas at Austin Student Branch)	Austin, TX (aiaa.org/2019-Region-IV-Student-Conference)	
3–5 Apr*	5th CEAS Conference on Guidance, Navigation & Control (2019 EuroGNC)	Milan, Italy (www.eurognc19.polimi.it)	
29 Apr–3 May	2019 IAA Planetary Defense Conference	Washington, DC (pdc.iaaweb.org)	
4–5 Apr	Region II Student Conference (Florida Institute of Technology Student Branch)	Cocoa Beach, FL (aiaa.org/2019-Region-II-Student-Conference)	
4–5 Apr	Region V Student Conference (University of Minnesota Student Branch)	Minneapolis MN (aiaa.org/2019-Region-V-Student-Conference)	
5–6 Apr	Region I Student Conference (University of Maryland Student Branch)	College Park, MD (aiaa.org/2019-Region-I-Student-Conference)	
5–7 Apr	Region III Student Conference (Cleveland State University)	Cleveland, OH (aiaa.org/2019-Region-III-Student-Conference)	

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

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
6–7 Apr	Region VI Student Conference (California Polytechnic State University Student Branch)	San Luis Obispo, CA (aiaa.org/2019-Region-VI-Student-Conference)	
7–9 May	AIAA DEFENSE Forum (AIAA Defense and Security Forum)	Laurel, MD	20 Nov 18
14 May	AIAA Fellows Dinner	Crystal City, VA	
15 May	AIAA Aerospace Spotlight Awards Gala	Washington, DC	
20–23 May*	25th AIAA/CEAS Aeroacoustics Conference (Aeroacoustics 2019)	Delft, The Netherlands	15 Oct 18
27–29 May*	26th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (elektropribor.spb.ru/icins2019/en)	
10–13 Jun*	18th International Forum on Aeroelasticity and Structural Dynamics	Savannah, GA (http://ifasd2019.utcdayton.com)	
12–14 Jun*	The Sixth International Conference on Tethers in Space (TiS2019)	Madrid Spain (http://eventos.uc3m.es/go/TiS2019)	
17–21 Jun	AIAA AVIATION Forum (AIAA Aviation and Aeronautics Forum and Exposition)	Dallas, TX	7 Nov 18
11–15 Aug*	2019 AAS/AIAA Astrodynamics Specialist Conference	Portland, ME (space-flight.org)	5 Apr 19
19–22 Aug	AIAA Propulsion and Energy Forum (AIAA Propulsion and Energy Forum and Exposition)	Indianapolis, IN	31 Jan 19
22–24 Aug	AIAA/IEEE Electric Aircraft Technologies Symposium (EATS)	Indianapolis, IN	31 Jan 19
21–25 Oct*	70th International Astronautical Congress	Washington, DC	28 Feb 19
2020			
6–10 Jan	AIAA SciTech Forum (AIAA Science and Technology Forum and Exposition)	Orlando, FL	
7–14 Mar*	2020 IEEE Aerospace Conference	Big Sky, MT (aeroconf.org)	
25–27 May*	27th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (elektropribor.spb.ru/en/conferences/142)	

AIAA Continuing Education offerings

**Meetings cosponsored by AIAA. Cosponsorship forms can be found at aiaa.org/Co-SponsorshipOpportunities.*

Class of 2019 AIAA Associate Fellows Honored

The Class of 2019 AIAA Associate Fellows were inducted at the AIAA Associate Fellows Recognition Ceremony and Dinner on 7 January at the Manchester Grand Hyatt San Diego in conjunction with AIAA SciTech Forum.

CLASS OF 2019 AIAA ASSOCIATE FELLOWS

Region I Class of **2019 Associate Fellows**

Region II Class of **2019 Associate Fellows**


Region III Class of **2019 Associate Fellows**


Region IV Class of **2019 Associate Fellows**


Region V Class of **2019 Associate Fellows**


Region VI Class of **2019 Associate Fellows**


Region VII Class of **2019 Associate Fellows**

AIAA Announces Its Class of 2019 Fellows And Honorary Fellows

AIAA has selected its Class of 2019 AIAA Fellows and Honorary Fellows. The induction ceremony will take place at the AIAA Aerospace Spotlight Awards Gala on 15 May 2019 at the Ronald Reagan Building and International Trade Center in Washington, DC.

Honorary Fellow is the highest distinction conferred by AIAA, and recognizes preeminent individuals who have had long and highly contributory careers in aerospace and who embody the highest possible standards in aeronautics or astronautics. The 2019 Honorary Fellows are:

G. Scott Hubbard, Stanford University

Dennis Muilenburg, The Boeing Company

Gen. Ellen M. Pawlikowski, U.S. Air Force

AIAA confers the distinction of Fellow upon individuals in recognition of their notable and valuable contributions to the arts, sciences, or technology in aeronautics or astronautics. The 2019 Fellows are:

Michael Amitay, Rensselaer Polytechnic Institute

Ella Atkins, University of Michigan

Brad Belcher, Rolls-Royce Corporation

Isaiah Blankson, NASA Glenn Research Center

Robert Canfield, Virginia Polytechnic Institute and State University

Meelan Choudhari, NASA Langley Research Center

Thomas Clemens, University of Texas at Austin

Fayette Collier, NASA Langley Research Center

Henry Garrett, NASA Jet Propulsion Laboratory

Greg Hyslop, The Boeing Company

Keoki Jackson, Lockheed Martin Corporation

Moriba Jah, University of Texas at Austin

Larry James, NASA Jet Propulsion Laboratory

Rakesh Kapania, Virginia Polytechnic Institute and State University

Jim Keenan, U.S. Army Aviation and Missile Research, Development, and Engineering Center

James Kenyon, Pratt & Whitney

David Klyde, Systems Technology, Inc.

Marc Kniskern, Sandia National Laboratories

Mark Miller, Dynetics, Inc.

Wing Ng, Techsburg, Inc.

Mark Pasquale, Lockheed Martin Corporation

Mostafa Rassaian, The Boeing Company

D. Brett Ridgely, Raytheon Company

Hanspeter Schaub, University of Colorado Boulder

Jaiwon Shin, NASA Headquarters

James Vasatka, The Boeing Company

Karen Willcox, University of Texas at Austin

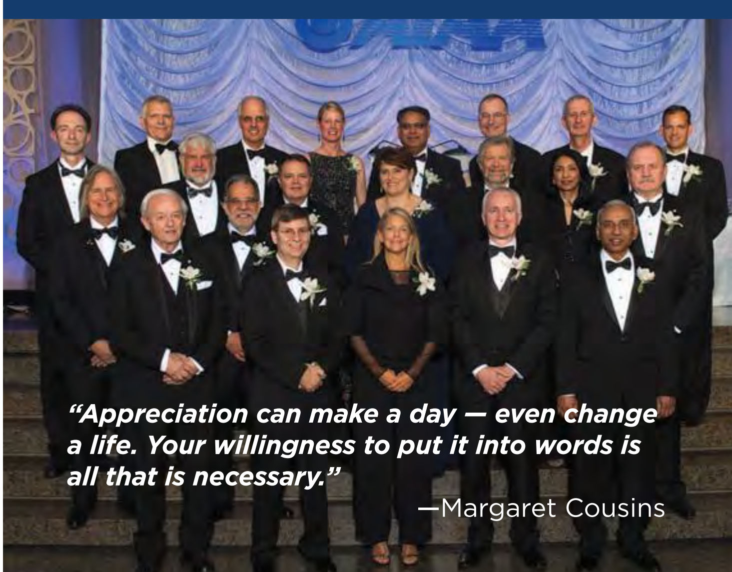
Thomas Yechout, U.S. Air Force Academy

Xinguo Zhang, Aviation Industry Corporation of China

In 1933, Orville Wright became AIAA's first Honorary Fellows. Today, AIAA Honorary Fellows and AIAA Fellows are the most respected names in the aerospace industry. For more information on AIAA's Honors Program or the AIAA Honorary Fellows or Fellows Program, please contact Patricia A. Carr at patriciac@aiaa.org.

Nominate Your Peers and Colleagues!

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



Candidates for SENIOR MEMBER

- Accepting online nominations monthly

Candidates for ASSOCIATE FELLOW

- Acceptance period begins 1 February 2019
- Nomination forms are due 15 April 2019
- Reference forms are due 15 May 2019

Candidates for FELLOW

- Acceptance period begins 1 April 2019
- Nomination forms are due 15 June 2019
- Reference forms are due 15 July 2019

Candidates for HONORARY FELLOW

- Acceptance period begins 1 January 2019
- Nomination forms are due 15 June 2019
- Reference forms are due 15 July 2019

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

AIAA
SHAPING THE FUTURE OF AEROSPACE

2019 AIAA Key Issues and Recommendations

The Aerospace & Defense (A&D) industry is critical to our nation's well-being, providing major contributions to national defense and homeland security, the economy, our quality of life, and education and learning. From the increasing growth and varied application of unmanned technology to the development of supersonic aircraft to the boom of activity in low Earth orbit by traditional and new commercial space players, there is much to look forward to in the coming years as government, industry, and academia together continue to imagine and create capabilities that transform our society. According to the Aerospace Industries Association, in 2017 the A&D sector:

- Supported more than 2.4 million jobs (842,900 directly employed), representing nearly 20 percent of the nation's manufacturing workforce
- Generated nearly $865 billion in economic output, of which $422 billion is attributed to the industry's supply chain
- Created $348.3 billion in value-added goods and services, or 1.8 percent of the U.S. GDP
- Paid out $220 billion in wages and benefits, with employees earning a salary 81 percent higher than the national average
- Received $83.9 billion from the federal government for research and development
- Exported $143 billion in goods and a positive trade balance of $85.9 billion (reducing the U.S. trade deficit by 10 percent)

The American Institute of Aeronautics and Astronautics (AIAA), the world's largest aerospace technical society, urges lawmakers to enact and sustain policies that will enhance a robust, technologically-proficient A&D sector. We strongly believe the accompanying key issues and associated actionable recommendations are crucial to the continued health of our industry, as well as the continued competitiveness and security of our nation. As we strive to represent our nearly 30,000 individual members, 95 corporate members, and the broader aerospace community, we welcome and encourage feedback—our motive is to strengthen the profession and serve as a valued resource for decision makers.

Funding Stability and Competitiveness

The A&D industry has experienced growth in recent years because of a strong market and increased defense spending; however, major challenges exist due to mounting budget deficits, trade policy uncertainties, and a lengthy acquisitions process, as well as foreign competitors investing heavily in military modernization and scientific research. Furthermore, the current unpredictable fiscal environment creates short-term perspectives, increasing the risk of delayed aerospace initiatives and the constant threat of important programs being terminated or scaled back to suboptimal levels. A return to a regular appropriations process coupled with a long-term perspective is needed immediately so that the nation, including the A&D industrial base, can begin work on initiatives critical to a secure and economically robust future.

Recommendations:

- Permanently eliminate the arbitrary budget caps and the sequestration process imposed on defense and non-defense discretionary spending.
- Provide sustained investment for basic scientific research in federal labs at levels consistent with maximizing economic growth and technological leadership.
- Provide the DOD with stable and predictable funding that supports efficient and effective multi-year acquisitions and operations.
- Streamline the defense acquisition process by tailoring oversight requirements to risk.
- Provide long-term authorizations and appropriations with top-line increases in the out years to properly fund all NASA missions in a balanced and predictable manner to meet short- and long-term program and mission requirements.
- Reauthorize the Export-Import Bank of the United States, and either confirm all open board appointments or allow the bank's single board member to approve transactions of more than $10 million.

R&D and Innovation

Since the dawn of aviation and through the advent of the space age, the United States has been the world leader in aerospace technologies. The federal government has played an important role in supporting research and development (R&D) efforts that have led to a myriad of scientific discoveries and innovations. Despite the recent uptick in federal funding for R&D to support the A&D industry, the overall trend over the last few decades has been downward. And while the United States still represents nearly half of global aerospace R&D spending, our foreign competitors continue to aggressively invest significantly more in technologies critical to aerospace and defense. Sufficient and sustained R&D investments are therefore crucial to maintain our preeminence in this sector and to create more high-paying jobs. Just as important is moving technologies from the laboratory into the marketplace through innovative new products and services that fuel growth, exports, and expanded employment.

Recommendations:

- Invest in computational and experimental capabilities to advance military and commercial R&D.
- Ensure sufficient and stable funding for federal programs specifically toward helping industry accelerate innovation and developing products in critical areas.
- Create programs that enable greater interaction and cooperative arrangements between federal labs and research centers, academia, and industry to develop technologies needed for innovation and growth.
- Support robust, long-term federal civil aeronautics and space research and technology initiatives funded at a level that will ensure U.S. leadership.
- Offer incentives for corporate research and commercialization of that research into new products and services.
- Ensure that federal agency R&D budgets provide sufficient funding so that the United States maintains long-term technical leadership and qualitative technical superiority.

Workforce Development and Enhancement

The U.S. A&D industry currently enjoys a prominent position in terms of global competitiveness and technical superiority; however, there are justifiable concerns as the sector faces a skills gap that will threaten our future standing in the world. According to the 2018 Aviation Week Workforce Study, nearly 30 percent of the nation's A&D workforce is over the age of 55 and 22 percent is younger than 35. The overall voluntary attrition rate is nearly 6 percent. And despite a major shift in the demographics of the United States the percentages of women and ethnic minorities working in A&D, at less than 25 percent and 5 percent, respectively, have not changed significantly in four decades.

Jobs in today's society are heavily reliant on technology, yet our education system is not currently structured to prepare students to be STEM-literate and adaptable to rapidly changing technologies. Additionally, many schools are underfunded, teachers receive inadequate support, and there is an absence of direct mentoring. These factors have helped create a national workforce crisis. Industry leaders and policymakers alike must tackle this crisis sooner rather than later so we as a society can address the forecasted demand for highly-skilled workers.

Recommendations:

- Pass legislation that enhances the pipeline of STEM-competent workers into the U.S. economy, including initiatives aimed at underrepresented demographics.
- Promote educational and training programs for both the existing workforce and new entrants, as well as encourage K-12 teacher recruitment and professional development, through federal incentives and/or grants.
- Support programs that specifically focus on technical jobs, improve the pipeline from high schools, and provide grants to carry out these activities.
- Incentivize industry and the military to be more directly engaged with evaluating and hiring military personnel transitioning to the civilian workforce, such as creating a standard to process and categorize military skill sets.
- Pass visa legislation that welcomes and retains highly-educated international professionals who earn advanced STEM degrees from U.S. colleges and universities.
- Reform the security review process to streamline investigations, increase oversight, prioritize mission critical investigations, and promote reciprocity among agencies, while protecting sensitive information and utilizing advanced technology to appropriately manage risk.

Attend CVD 2019

Registration is open for AIAA members who would like to attend the 2019 Congressional Visits Day (CVD) program. Attendees will gather on 20 March in Washington, DC, to promote the Institute's Key Issues. A training webinar will be held on 5 February, and a formal, in-person training session will take place 19 March at Lockheed Martin's Global Vision Center in Arlington, VA.

Register at aiaa.org/cvd2019

For more information, contact Steve Sidorek, at steves@aiaa.org or 703.264.7541.

AIAA Diversity Scholars Program

MAKING AN IMPACT

Aerospace professionals seek the best answers to tough problems. We've learned that teams composed of members with diverse backgrounds and experiences are better problem solvers than homogeneous groups. That's why the AIAA Foundation, collaborating with the AIAA Diversity Working Group, started the Diversity Scholars Program to bring students from underrepresented backgrounds in the aerospace industry to AIAA forums. We also know from research that direct experience with aerospace has set many current aerospace professionals on their current path. Last year, 70 Diversity Scholars attended AIAA forums!

Fifteen Diversity Scholars attended the 2019 AIAA SciTech Forum in San Diego. Thank you to Aurora Flight Sciences, a Boeing Company, for partnering with the AIAA Foundation to fund the scholars' all-expenses-paid trip!

For more information about our educational programming or to make a donation, visit aiaafoundation.org. Information about AIAA's diversity and inclusion plan is found at aiaa.org/diversity-and-inclusion.

News

2019 International Student Conference Winners

The awards were presented by Dan Dumbacher, AIAA Executive Director (right) and the keynote speaker was J. D. McFarlan III, Vice President, F-35 Test & Verification, Lockheed Martin (left). The winners, from left to right, are Margaret Linker (Team Category), Matthew Schwartz (Masters Category), and 2nd Lt. Anna Demoret (Undergraduate Category).

The AIAA Foundation International Student Conference takes place annually at AIAA SciTech Forum. Students who have won first place in the Regional Student Conferences present their papers at a professional technical conference. The conference offers the students a chance to showcase their research at an event where they can network with potential employers and colleagues. The 2019 International Student Conference was held on 7 January in conjunction with AIAA SciTech Forum in San Diego, CA. The awards were presented by J. D. McFarlan III, Vice President, F-35 Test & Verification, Lockheed Martin Aeronautics Company. Thank you to Lockheed Martin Corporation for sponsoring the 2019 International Student Conference.

Undergraduate Category

2nd Lt. Anna C. Demoret and Charles F. Wisniewski, United States Air Force Academy
The Impact of a Notched Leading Edge on Performance and Noise Signature of Unmanned Aerial Vehicle Propellers

Master's Category

Matthew J. Schwartz and John D. Schmisseur, University of Tennessee Space Institute
Characterization of Near-Muzzle Ballistic Flow Fields using High Speed Shadowgraphy

Team Category

Purdue University (Steven M. Pugia, Ryan J. Clay, Matthew F. Fuehne, Margaret M. Linker, Noah C. Franks, Benjamin J. Davis, and Katherine L. Fowee)
Liquid Water Micropropulsion System for Small Satellites

Dates for the 2019 Regional Student Conferences can be found on the Calendar (pp. 48-49). For information on the AIAA Foundation International Student Conference, contact Rachel Dowdy at 703.264.7577 or racheld@aiaa.org.

University of Colorado/ LASP Hosts AIAA Rocky Mountain Section Annual Technical Symposium

By Wesley A. Kenison

On 29 October 2018, the AIAA Rocky Mountain Section held its 7th Annual Technical Symposium (ATS) at the University of Colorado (CU) South Denver Campus. Hosted by CU and the Laboratory for Atmospheric and Space Physics (LASP), the symposium featured 22 speakers, 3 panels, 10 poster presentations, 2 keynote speakers, and an exhibitor marketplace with 20 vendor/sponsor booths.

The full-day conference began with an opening address by Colorado Aerospace Champion Jay Lindell (Major General, USAF, retired), welcoming the crowd of nearly 200 attendees. The opening was followed by a panel on Space and Global Security. After the morning panel, the conference broke out into presentations on Unmanned Aircraft Systems and Advanced Manufacturing topics, followed by a panel on the Commercialization of Space. The morning presentations were rounded out with presentations on Aeronautics and Astronautics topics.

The keynote luncheon was highlighted with a presentation by United Launch Alliance (ULA) President and CEO Salvatore (Tory) Bruno, who spoke about the development and progress of ULA's new Vulcan Rocket and ACES upper stage. Bruno also discussed the development of Sensible Modular Autonomous Return Technology (SMART) reuse concepts, which aims to recover the booster engines after first stage burnout.

1


2

A big focus of the day's events was the subject of space weather. Afternoon presentations included a panel on the topic featuring experts from LASP, NOAA, NCAR, Ball Aerospace, and the National Solar Observatory, followed by a presentation on the Next Generation Defense Weather Mission being developed at Ball Aerospace.

The day ended with a keynote presentation by Bradley Cheetham, President and CEO of Advanced Space. In his presentation, Mr. Cheetham discussed the development of a Cislunar Autonomous Positioning System (CAPS) that he hopes will become a critical piece of infrastructure enabling cislunar navigation.

Full details of the conference, including abstracts of all presentations can be viewed on the ATS website at **aiaa-rm.tech**.

3

1 Space Weather Panel

2 ULA President and CEO Tory Bruno

3 ATS Exhibitor Marketplace

Photos by Christopher Zeller

Long-Time AIAA Member Dick Russell Honored at AIAA Cape Canaveral Event

By Jacob Shriver, AIAA Cape Canaveral Section Communications Officer

Pictured (left to right): G. Alan Lowrey (Aerospace Outreach Group Director), Dick Russell, Kurt Polzin (Region II Director), and Matthew Zuk (AIAA Cape Canaveral Section Chair)

The AIAA Cape Canaveral Section and Region II leadership hosted an event honoring Richard "Dick" Russell on 17 September at Rising Tide Tap & Table in Cape Canaveral, FL. The event, which was planned in complete secrecy to the man of the hour, celebrated Mr. Russell's many career accomplishments and AIAA service. With the AIAA SPACE Forum being held in Orlando, it was the perfect chance to celebrate with members throughout Region II. AIAA members in attendance included Region II Director Kurt Polzin, former Region II Director G. Alan Lowrey, and member representation from Huntsville, Atlanta, Savannah, and Cape Canaveral sections.

Polzin and Lowrey (and former Region II Director Mark Whorton, who could not attend the event) presented Mr. Russell with a Saturn V model, personalized with the inscription "In recognition of longtime service to AIAA and with sincere personal thanks for sharing the gifts of his experience, insight, advice, and leadership." Mr. Russell reminisced on his AIAA membership since 1965 (yes, 1965!) and gleefully described his memories of watching Saturn I-Bs and the first Saturn V ignite the Space Coast. Mr. Russell has a long history of AIAA accomplishments including AIAA Associate Fellow, Region II Director (1984–1987), Student Activities Committee (1989–1996), Young Professional Section Officer (1993), Region II Deputy Director–Finance (2008–2018), and 2015 recipient of the Special Service Citation for years of service as Region II DD–Finance. Mr. Russell resigned his deputy director position last spring; however, he continues to regularly support his local Cape Canaveral Section and Region II.

Congratulations, Dick, on an amazing AIAA and professional career!

Inspiring Positive Societal Impact for Shaping A Better World

By Dr. Amir S. Gohardani, Chair, SAT IOC

On 28 November 2018, a networking/career development event was held at California State University, Fullerton (CSUF) to inspire students to engage with the AIAA Orange County (OC) Section and to educate them about the Society and Aerospace Technology Integration and Outreach Committee (SAT IOC) and other AIAA activities. In a presentation given by Dr. Amir Gohardani, undergraduate and graduate studies were discussed in addition to research endeavors and the societal impact of aerospace technology on society.

The event was organized by the AIAA CSUF Student Branch and revolved around career advancement in a competitive market. Attendees were encouraged to attend AIAA OC section's local ASAT conference as well as AIAA's national forums. Although the majority of the participants were engineering majors, the event was also attended by students of other majors.

SAT IOC constantly strives to enable bridges between the general public and their understanding of aerospace technology and the committee constantly adapts its methods to reach a larger portion of society. This event partnership with the AIAA OC Section to inspire students toward shaping a better world was indeed greatly appreciated by SAT IOC.

Top: CSUF students with Dr. Gohardani (middle) during the event.

Bottom: AIAA CSUF Student Branch President Darove Prado (left), Dr. Gohardani (middle), and Jordan Andia, AIAA CSUF Student Section Vice President (right) during the event.

Bob Welge at the 2018 Mars Society Annual Conference.

A New Beginning for the AIAA OC Section

By Dr. Amir S. Gohardani, AIAA OC Section Chair Emeritus

2019 marks a new beginning for the AIAA Orange County (OC) Section in Southern California. Most recently the section has been recognized by the following three recognitions in the AIAA Large Section category:

- 1st Place: STEM Category
- 2nd Place: Membership
- 3rd Place: Outstanding Section

Bob Welge, an AIAA Associate Fellow and one of the section's most active members, has held a crucial role in assisting the section reaching its second-place membership recognition. Mr. Welge tirelessly works as the section's membership officer and as a frequent RAC representative. In the past, he has also helped out as the section Treasurer and he has diligently served the council by providing his support to multiple numbers of officer positions. He was recently awarded emeritus status by AIAA and was recognized for 50 years of membership. He continues to assist the section by building on the section's tradition of partnering with other AIAA sections. An example of such collaboration was last showcased during the 2018 Mars Society Annual Conference in Pasadena where he invited new members to join AIAA activities in two local day events with the AIAA Los Angeles/Las Vegas section.

AIAA Associate Fellow Welge was recognized for his AIAA membership.

The AIAA OC Section also partnered with the AIAA Society and Aerospace Technology Integration and Outreach Committee (SAT IOC) for the purposes of inspiring members to engage in additional AIAA OC section activities through a recent event held at California State University, Fullerton. For more information about this event, please refer to the SAT IOC article.

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- Supported more than **400 student conferences** engaging **13,000 students**.
- Sponsored design competitions that have attracted more than **11,000 college students**, giving them the chance to apply engineering skills outside of the classroom.
- Enabled more than **140,000 student members** and **9,000 Educator Associates** to continue learning about aerospace science and technology.

For more information and to make a gift, please visit **aiaafoundation.org**

The AIAA Foundation made an impact on the Diversity Scholars pictured above by helping them attend AIAA SciTech Forum so they could learn about their future workforce!

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1919

Feb. 1 Aircraft Transport & Travel Ltd. starts flying cargo between England and Belgium at the request of the Belgian government. AT&T's converted Airco DH.9 aircraft, flown by military pilots, carry loads of woolen and cotton goods, food and other supplies desperately needed by the Belgian people after World War I battles devastated the country. R.E.G. Davies, **A History of the World's Airlines**, pp. 16-20.

Feb. 5 Germany's Deutsche Luft-Reederei becomes the world's first civilian passenger airline and operates among Berlin, Leipzig and Weimar. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 9.

Feb. 21 The Thomas-Morse MB-3, the first American-designed mass-produced fighter aircraft, makes its first flight. In these early tests, it reaches a top speed of 264 kph (164 mph), which betters European counterpart aircraft. Flown by Frank H. Burnside from its field in Ithaca, New York, the "Tommy Morse" is powered by a 300-horsepower Wright H, which is a license-built Hispano H V-8. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 10.

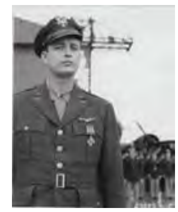
1944

Feb. 2 Soviet leader Joseph Stalin agrees to provide six bases for American bombers and fighters that will enable the U.S. Army Air Forces to strike deeper into Germany than possible before on shuttle bombing missions. K.C. Carter and R. Mueller, compilers, **The Army Air Forces in World War II**, p. 263.

Feb. 2 As part of Operation Crossbow, 96 U.S. Consolidated B-24 heavy bombers strike such German V-weapon sites as Saint-Pol, Siracourt and Watten in occupied France. The next day, 52 Martin B-26 medium bombers continue the attack, with more attacks occurring throughout the month. K.C. Carter and R. Mueller, compilers, **The Army Air Forces in World War II**, pp. 263, 267.

Feb. 16 A Curtiss XSC-1 Seahawk makes its first flight and subsequently becomes the last of a long line of U.S. Navy scout aircraft. Peter M. Bowers, **Curtiss Aircraft: 1907-1947**, pp. 446-449.

Feb. 17 The first night-bombing attack from a U.S. aircraft carrier is carried out when a dozen radar-equipped Grumman TBF-1C Avengers take off from the USS Enterprise and attack Truk, an island in the South Pacific. Rene J. Francillon, **Grumman Aircraft Since 1929**, p. 178.



Feb. 18 Col. Elliott Roosevelt, a son of President Roosevelt and the director of reconnaissance for the U.S. 9th Air Force, is named commanding officer of the new Photo Reconnaissance Wing (8th Reconnaissance Wing, Provisional) based in Cheddington, England. K.C. Carter and R. Mueller, compilers, **The Army Air Forces in World War II**, p. 274.

Feb. 20 The U.S. Army Air Forces' designated "Big Week" begins when over 1,000 planes of the 8th Air Force are sent to attack German fighter aircraft production centers. K.C. Carter and R. Mueller, compilers, **The Army Air Forces in World War II**, p. 276.

Feb. 22 A.J.A. Wallace Barr, one of the first to originate airplane "dope" in about 1911, is killed along with his wife when a German bomb strikes their home in Sunningdale, England. Prior to his discovery of the cellulose varnish known as dope, British aircraft wings were usually made taut by a flour paste. Wallace Barr gained British rights for the varnish and sold it under the name Cellon, which was widely used in World War I. He also developed a special enamel for all-metal aircraft. **The Aeroplane**, March 3, 1944, p. 234.

Feb. 28 The first German Wasserfall liquid-fuel anti-aircraft missile is test flown from Peenemunde. It stands 7.5 meters tall, has a fin span of a meter, a thrust of 76,331 newtons (17,160 pounds), a horizontal range of 26.5 kilometers, and a ceiling of 18 kilometers (60,000 feet). The Wasserfall is judged to have been potentially a more effective weapon than the V-2, but it never became operational. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 47.

During February
The first unpainted Boeing B-17G Flying Fortresses scheduled for combat duty come off the assembly lines. The lack of paint makes the planes 27 kilograms (60 pounds) lighter and enables them to fly faster by several kilometers per hour. The only exterior paint is black patches on surfaces that would reflect sunlight in the airmen's eyes. **Aero Digest**, Feb. 15, 1944, p. 187.

1969

Feb. 2 NASA astronaut Frank Borman and his family leave on a U.S. Air Force jet for an 18-day presidential goodwill mission to Europe in honor of the Apollo flight to the moon and back. Borman was the commander of Apollo 8, the first mission to fly around the moon. The Bormans are to visit London, Paris, Brussels, The Hague, Bonn, West Berlin, Rome, Madrid and Lisbon. During these visits, Borman is presented to England's Queen Elizabeth II, has an audience with Pope Paul VI, and is accorded other honors that are also extended to his crew members. **Washington Star**, Feb. 2, 1969, p. A-3; **Washington Post**, Feb. 22, 1969, p. A2.

Feb. 7 Royal Crown Cola International announces that former astronaut John Glenn has become its president. Glenn had been chairman since January 1967. **Washington Post**, Feb. 8, 1969.

Feb. 9 The Boeing 747 makes its first flight, of 1 hour, 16 minutes, from Paine Field, adjacent to Boeing's new Everett, Washington, factory near Seattle. It is flown by 747 project pilot Jack Waddell, and is followed by a chase plane, a Boeing-owned Canadair Sabre Mk. 5. The $20 million plane is a 490-passenger prototype. **Aviation Week**, Feb. 17, 1969, p. 26.

Feb. 11 The Soviet Union orders 100 "space pens" developed for U.S. astronauts and 1,000 pressurized ink cartridges that enable the pen to write in weightlessness according to the pen's inventor, Paul C. Fischer. **Washington Post**, Feb. 13, 1969, p. D24.

Feb. 13 John A. O'Keefe, a planetary scientist and expert in satellite mapping at NASA's Goddard Space-flight Center in Greenbelt, Maryland, starts preparing the first precise maps of Tibet, using photos taken of the country from 160-kilometer altitudes, in addition to data obtained between the 1890s and 1935 by Swedish explorer Sven Hedin. **New York Times**, Feb. 13, 1969, p. 1.

Feb. 24 Mariner 6 is launched to Mars by an Atlas Centaur booster from Cape Kennedy, Florida. The 408-kilogram spacecraft will fly to within 3,200 kilometers of the planet on July 31. The data obtained by the Mariner will be used to develop scientific packages for NASA's Viking project. **Aviation Week**, March 3, 1969, p. 19; **Flight International**, March 13, 1969, p. 418.

Feb. 26 NASA launches the ESSA 9, for the Environmental Science Services Administration's ninth meteorological satellite in its Television & Infra-Red Observation Satellite system, on a three-stage Thrust-Augmented Thor-Delta booster. When placed in a geosynchronous orbit, ESSA 9 provides daily advanced-vidicon-camera pictures of the world. **ESSA press release ES-69-9**.

During February 1969

- It is announced that new Soviet-built SA-2 Guideline missile installations are being built in eastern Cuba in the vicinity of the large U.S. Navy base. These sites are the first major new SA-2 installations detected in Cuba since the missile crisis in the fall of 1962. **Aviation Week**, Feb. 24, 1969, p. 15.
- A Soviet Mi-12 compound helicopter sets several world altitude-payload records at an airfield near Moscow. The Mi-12 has four wingtip-mounted Soloviev D-25V turbine engines. **Aviation Week**, March 24, 1969, p. 22.
- North American Rockwell delivers its first T2-C Buckeye jet trainer aircraft to the U.S. Navy. North American is building 84 of the T-2Cs for Navy under a $34 million contract. The first version of the aircraft entered service in 1959 as the T2J-1 and since that time every jet-qualified naval aviator and every Navy flight officer until 2004 received training in the Buckeye. **Aviation Week**, Feb. 10, 1969, p. 19.

1994

Feb. 3 For the first time, a U.S. space shuttle, the Discovery's STS-60 mission, carries a Russian cosmonaut, Sergei Konstantinovich Krikalev. Five U.S. astronauts accompany Krikalev. NASA, **Astronautics and Aeronautics, 1991-1995**, pp. 473, 711.

Feb. 3 NASA retires its last Lockheed F-104 Starfighter aircraft. It was used to simulate the flight characteristics of the X-15 and to conduct biomedical research. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 474.

Feb. 4 Japan's H-2 booster is launched; it is the first Japanese space agency launcher built entirely in Japan without foreign technology. It has Japan's first cryogenic (liquid oxygen/liquid hydrogen) engine, the LE-7, in stage one, and two solid fuel strap-on boosters. **Aviation Week**, Feb. 14, 1994, p. 30; **Space News**, Feb. 7-13, 1994, pp. 1, 20.

Feb. 18 The FAA approves airlines' use of 24 military GPS satellites, allowing the companies to save many millions of dollars by flying more accurate and efficient routes. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 479.

TWYMAN CLEMENTS, 31

Co-founder and chief executive, Space Tango

When Twyman Clements and his three brothers launched model rockets as boys on their Kentucky family farm, he didn't think he would ever have a chance to build spacecraft. In fact, he tried being a prep cook for a while in a restaurant. But that wasn't for him, so he followed his brothers to the engineering program at the University of Kentucky. There he heard about Kentucky Space, a nonprofit consortium of universities and public and private groups. Now, Clements leads Space Tango, a 15-person commercial startup in Lexington that began at Kentucky Space. It is focused on microgravity research and manufacturing on the International Space Station and in an autonomous manufacturing facility the company plans to operate in the mid-2020s for advanced materials and biomedical devices.

How did you get into the business?

When I was in college, Kentucky Space was building the state's first educational cubesat, KySat-1. It launched on NASA's first Educational Launch of Nanosatellites mission. Kentucky Space offered great opportunities because it did everything from balloons to suborbital rockets, cubesats and International Space Station work. I got to see the cubesat community up close when it was very small and watch it become an industry. In late 2009, Kentucky Space had an opportunity to conduct experimental work on ISS, which led us to pivot and focus more on research, development and manufacturing on that platform. That's where the idea for Space Tango originated. We asked, "How could we do this differently?" Kentucky Space built a few more cubesats, which I managed or worked on. After KySat-2 launched in November 2013, we went back to the ISS idea as we'd seen promising applications, particularly in the biomedical area. We developed the TangoLab product line. TangoLab is a 58-centimeter-by-46-centimeter platform that houses CubeLabs, 10-centimeter cubes with power and communication links for microgravity experiments. Space Tango spun out of Kentucky Space as our ambitions were in the commercial marketplace. Since our first operational launch on a SpaceX space station commercial resupply mission in February 2017, we've sent 64 payloads and 104 experiments to the space station. Our long-term view is using microgravity to build high-value products in space for Earth.

Imagine the world in 2050. What do you think will be happening in space?

I see an analogy with the internet from the '90s through the middle of this decade. The advances and new players in the launch vehicle market are like the broadband or fiber being laid for the internet. They're the enablers. The next few years will show us what business models can come out of that greater access to space, whether that be tourism, new methods for data gathering via satellites, mining, etc. In this analogy, once the high-speed internet was available, more valuable companies could be built on top, offering new applications in commerce, video sharing, social networking and all the other things we do.

BY DEBRA WERNER | werner.debra@gmail.com

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