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SMARTER

Collision avoidance

Keeping you safe in crowded skies. PAGE 22

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AEROSPACE AMERICA

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Tom Risen

As our staff reporter, Tom covers breaking news and writes features. He has reported for U.S. News & World Report, Slate and Atlantic Media.
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DEPARTMENTS


National Park Service

▲ **Part of the fuselage** from a Lockheed L-1049 passenger plane lies in the Grand Canyon after it collided with a DC-7 in June 1956.

The unexpected impacts of collision avoidance

In the U.S. in the 1950s, the skies must have seemed so vast that experts assumed airliners could avoid collisions provided pilots kept their eyes peeled. This belief was proved deadly wrong in 1956, when two airliners collided over the Grand Canyon, killing 128 people.

That piece of history, discussed in our cover story beginning on Page 22, explains a lot about today.

No wonder the FAA insists on a step-by-step approach to allowing drones and larger unmanned aircraft to fly regularly in the national airspace. No wonder the FAA and its partners are determined to create versions of collision avoidance software that can handle the anticipated growth in passenger flights and also the exploding demand for drones.

The FAA has learned from history, but the lessons should extend beyond aviation. The space industry might unwittingly be setting itself up for the equivalent of the Grand Canyon collision. Thousands of small satellites are about to be launched into orbit without clear plans for preventing collisions and debris. A devastating wake-up call in orbit would be much harder to clean up afterward. It would be as though the debris from the Grand Canyon collision were circulating over the canyon decades later. Once the wake-up call is heard, the satellites can't land to have new equipment installed.

The history of collision avoidance in aviation also raises questions about the willingness of humans to place trust in technology. In the case of an airliner collision over Germany in 2002, a problem was compounded when the pilot on one of the planes didn't follow the advisory sounded by his collision avoidance software.

Will these kinds of trust issues crop up more often as designers add new levels of artificial intelligence and automation to aircraft, or will pilots and the rest of us learn to accept software in control? If I had to guess, I'd say that humans won't change and that the best automation software will be written in a manner that recognizes that we have trust issues.

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

Recognizing and Honoring Members is *Everyone's* Responsibility

Having just finished presiding over my first AIAA Spotlight Awards Gala, I was reminded that one of the things I enjoy most about being AIAA President is presenting awards and celebrating our members' achievements. Each AIAA award and honor that the members of our community earn involves years—sometimes entire careers—of dedication, determination, and drive. This individual and team research and work leads to the concepts, advancements, and breakthroughs that further integrate aeronautics and astronautics into the fabric of our global society. Awards recognize the outstanding efforts of our members and sometimes those outside our community who have positively influenced aerospace. And the recognition is especially significant because recipients' peers nominate them; peers who have evaluated their work and found it worthy of recognition from the community – a lasting testament to the individual's impact on the aerospace arts and sciences.

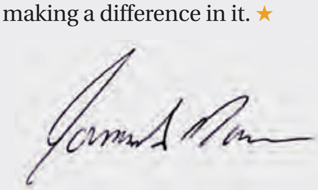
AIAA presents scores of awards each year that recognize the best and brightest achievements across the aerospace enterprise. Our premier awards are presented at the AIAA Aerospace Spotlight Gala each spring, while the technical excellence awards are presented at our forums. We also recognize excellence in education through awards to students and teachers. Student recognition through paper competition awards, scholarships, and grants encourages the future members and leaders of our Institute and may help them finish their education or even get their first job in the industry! There also are awards that allow distinguished lecturers to share their research, contributions, and technological insights with AIAA members.

As Sandy and I discussed in our Executive Report in the AIAA Annual Report, the Institute has a strong and abiding commitment to diversity and inclusion in its workforce, its membership, and the overall industry. Aerospace is best advanced by the leadership and contributions of men and women of diverse backgrounds, beliefs, and cultures. To that end, the Institute announced earlier this year that we have established a new annual award. Created by the Institute's Diversity Working Group, the AIAA Diversity and Inclusion Award will recognize "an individual or group within AIAA who has devoted time and effort and made significant contributions to the advancement of diversity and inclusion within the Institute." The Institute will present this new honor at our SciTech Forum each January. The award challenges each of us to do more to ensure our community remains diverse, thriving, and welcoming to all who want to improve the future.

Beyond certificates, lectureships, scholarships, grants, paper competition awards, and medals, AIAA also singles out individuals for membership honors through our Associate Fellows, Fellows, and Honorary Fellows programs. These membership ranks signal achievement in the aerospace arts and sciences that go beyond ordinary contributions to the field and honor those who have had long and highly contributory careers in our community. These advancements—which are peer nominated and peer selected—are recognition of a member of professional distinction who has made a difference to the Institute or industry. Each advancement in rank is a "badge of honor" that guides those just starting out in our community, showing them that the Institute will notice and reward their hard work and steadfast devotion to improving the aerospace arts and sciences. They are important career honors to aspire and work toward.

The Institute is always working to improve the Honors and Awards Program and we welcome your input and involvement. We also owe the dedicated women and men on the selection committees a debt of gratitude for all the time they spend doing the important work of reviewing nominations—they are a huge part of that process. But for the Institute to truly recognize the best of the best in the aerospace community, WE NEED YOU! Your active participation in the process is critical to ensuring that we identify those who deserve that recognition. All AIAA members can nominate an individual for an award and for Associate Fellow and Fellow. Honorary Fellows must be nominated by a Fellow or current Honorary Fellow. Each of you knows someone who is worthy of having their work honored by the Institute. I challenge you, in the next year, to commit to take the time to nominate a colleague, a mentor, a student for an AIAA honor or award. They, and you, will appreciate your efforts.

Taking the time to ensure that those who deserve our praise receive it is an important part of strengthening the spirit of the aerospace community and allows us to celebrate those who are making a difference in it. ★



Jim Maser, AIAA President

3-D center joins real, virtual design

BY JOE STUMPE | jstumpe@cox.net

Now that Dassault Systems, the France-based engineering software company, has opened its 3D Experience Center in Kansas together with Wichita State University and the National Institute for Aviation Research, clients are expected to perform ground-breaking design research, starting with Airbus, which almost simultaneously dedicated a new building at the university's Innovation Campus.

Dassault and its partners describe the center as a place where the virtual and real worlds of the aerospace industry are combined in a center that doubles as an educational facility for WSU. Designs can be developed in computer simulations and then these can be 3-D printed and tested.

Dassault expects to work closely with Airbus, but if all goes as planned, that will just be a start. "The university is working on bringing another 30 Airbuses here," said Michel Tellier, vice president of aerospace and defense for Dassault, speaking to reporters before the April opening. The center's partners showed off the facility to industry executives and journalists.

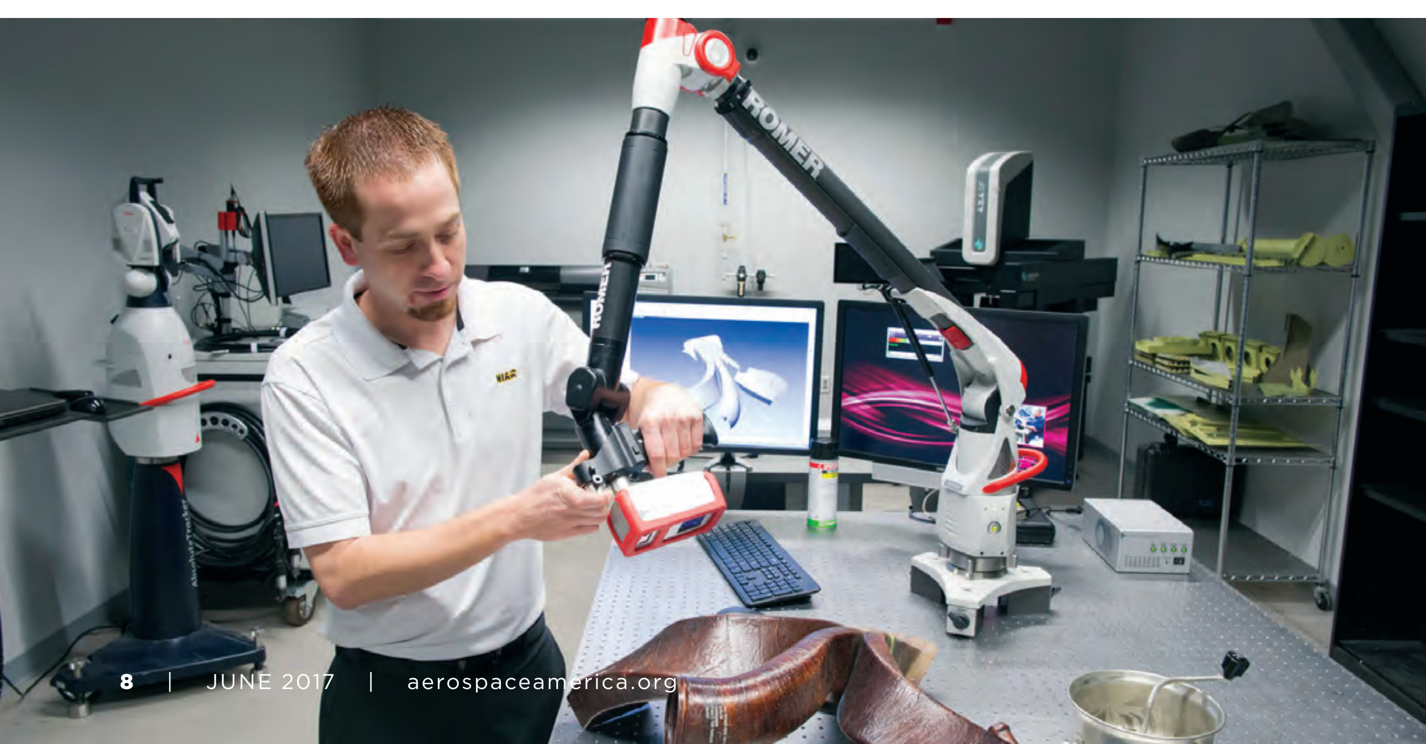
The site has six spaces to move clients through the process of development and production design. This setup "lets you virtually innovate and then to go to another lab [in the center] to physically get to where you want to go," explained Dassault's Brian Christensen. Addressing the industry attendees, Christensen said designers have "set an audacious goal to make a dramatic reduction" in program lifecycle costs and "you're going to need process guidance and collaboration to do that."

Attendees were shown the concept refinement lab, where materials can be virtually evaluated for properties including elasticity, strength and thermal characteristics. That data will help engineers define the kind of physical models required for efficient testing, which should save time and money.

Attendees also visited the 3D CAVE, a high-definition virtual environment where clients can simulate manufacturing processes. "The ultimate goal is prove out the entire mission and system before you have to build something," said Jeff Fisher, the 3D CAVE manager and a NIAR employee. Once a client provides the 3-D design, he says, a simulation model can be created "by the time you drive here."

To make the case, the presenters showed attendees a drone and its gimbal camera mount that were made at the center. They explained that the original gimbal was redesigned and 3-D printed to reduce the drone's weight by 200 grams.

The drone was assembled in the center's multirobotic additive manufacturing space, where six multifunction robots work together on an assembly line, helping clients envision what a NIAR staffer called the "factory of the future." ★



▼ **Chris Rempe**, manager of the Reverse Engineering Labs at Wichita State University's National Institute for Aviation Research, uses a portable coordinate measuring machine to scan an aircraft part to generate computer-aided design data. The lab is part of the 3D Experience Center.

Wichita State University

Aireon

Aireon: Test flights read loud and clear

BY TOM RISEN | tomr@aiaa.org

▲ **This is one of Aireon's** Automatic Dependent Surveillance-Broadcast receiver payloads before it was installed on an Iridium Next satellite.

The strategy was an ambitious one in March when the FAA, Nav Canada and Polaris Flight Systems flew planes through U.S. and Canadian airspace to put Aireon LLC's forthcoming aircraft tracking service through its first real-world tests.

Aireon, a joint venture of the Iridium satellite company and Canada's air traffic control provider Nav Canada, hoped the tests would verify that radio receivers on Iridium's first batch of new satellites could accurately collect thousands of Automatic Dependent Surveillance-Broadcast messages.

ADS-B messages, whose data includes an aircraft's location and velocity, are at the heart of the FAA's Next Generation Air Transportation initiative and Aireon's business plan. Right now, those messages only flow into air traffic networks when planes are in range of an antenna tower or other planes equipped with ADS-B "in" receivers. That leaves coverage holes over the oceans and remote regions. Aireon aims to plug those gaps by collecting ADS-B messages in orbit and selling this "air traffic surveillance" service to customers such as the tracking firm FlightAware. Malaysia Airlines in April announced it would indirectly receive Aireon's data once it is shared by FlightAware with other aircraft location providers.

One of the test flights was particularly challenging. A Bombardier "flying laboratory" jet managed by the FAA took off from Atlantic City, New Jersey, and flew over the Atlantic Ocean and through the Washington, D.C., and New York flight information regions.

"The East Coast of the United States has a huge air traffic load and most every air transport aircraft is not only transponding or transmitting the 1090 MHz ADS-B message, it's also got another device called a TCAS [traffic collision avoidance system] that uses the same spectrum," explains Aireon Chief Technology Officer Vincent Capezzuto.

After spending weeks analyzing the data, Aireon made an upbeat announcement on May 3. Its satellite-based network accurately decoded the messages from the test flights, keeping the company on track to make its service operational in 2018 once Iridium finishes launching the Iridium Next satellites that will replace its existing constellation.

A test flight conducted by Nav Canada through the Montreal, Winnipeg and Edmonton flight information region posed a somewhat easier challenge, because the north is less congested. Polaris Flight Systems of Arizona made the third flight with a Beechcraft Bonanza, a plane popular among general aviation enthusiasts. The FAA has mandated that all aircraft in most U.S. airspace, including general aviation planes, must be equipped by January 2020 with ADS-B Out transmitters.

"When you introduce something like space-based ADS-B that offers a bird's-eye view looking down, there are no gaps," Capezzuto says, adding that the service will give rescue teams more time to respond to plane accidents, and airlines will have more data to plan efficient flights.

Seven SpaceX launches scheduled during the next 12 to 15 months will be needed to complete Iridium's constellation for a total of 66 satellites and nine in-orbit spare satellites. The FAA is offering a $500 rebate to aircraft owners and businesses to ease the installation of ADS-B Out equipment. ★

"You need to have nuclear reactors to power your space vessel. I just don't see a solar-powered ion drive having enough beef to it," says best-selling author Andy Weir, opining on a spacecraft to reach Mars.

NASA

The future according to Weir

Andy Weir's lifelong love of space propelled him to begin writing "The Martian" as a free blog in 2009 and then as a novel. Weir made a fortune in 2013 when he sold the rights for his tale of a stranded astronaut to a publishing house and filmmakers who turned the story into a best-selling book and an Oscar-nominated movie. Weir has no intention of being a one-hit wonder. He's following "The Martian" with a new science fiction novel due out in November, and he's trying to break into television, although CBS passed on the pilot of his space-themed drama "Mission Control." Weir's space fascination drives him to research and emphasize the science aspect of science fiction. That hard-science approach helped him craft a realistic survival story that made it easy to identify with a protagonist who, in Weir's words, had "no real character flaws." That said, Weir says to expect more character development in his next works. I interviewed Weir on the phone at his home in California about his new projects and views about colonizing Mars.
— *Tom Risen*

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ANDY WEIR

BACKGROUND: Author; software engineer for 25 years, until 2014, including stints with Sandia National Laboratories, AOL, Blizzard Game Studios, MobileIron

NOTABLE: His novel "The Martian," first written as a free blog then self-published in 2011 as an e-book, has sold 3 million copies. The film adaptation of "The Martian" grossed $630 million. His next novel "Artemis," about a city on the moon, is scheduled to be published Nov. 14.

AGE: 44

RESIDENCE: Mountain View, California

EDUCATION: Attended University of California, San Diego

IN HIS WORDS

Building colonies on the moon and Mars

I would love to see the human race expand farther out. I think it's a necessity for us. Not just a necessity really, but also it's a fundamental drive that we have. One of the reasons the human race is top dog on this planet is because we do have that tendency to spread out and go just to see what's over that next hill, and to colonize and move outward. That's why we're one of the few species on this planet that lives on all the continents. That's how we do things, and that was an evolved advantage of ours. By spreading out and living all over the place, all over the whole planet, we made it so that we were immune to any localized disaster.

Space exploration and survival of the human species

I don't see that as the argument for going to Mars. I hear it a lot and I admit even sometimes I say it, but there's a slight distinction between what I say and the survival argument. I don't believe it is critical to human survival that we go to Mars. I'm just saying that it is inevitable that we'll go to Mars because of a survival instinct that is endemic to our species.

Scientific accuracy in "The Martian"

I'm a science dork myself, and so it always kind of screws my suspension of disbelief when there's like, blatant scientific inaccuracies. I don't mind if you have a warp drive, right? I'll take that as a given, but if people are walking around on Mars without helmets, then I get really annoyed. So it's weird the way a nerd's mind works, but that's how it is. So I set out to make as accurate a sci-fi story as I could, partially just to kind of satisfy my own suspension of disbelief issues, but also because I knew my readers at the time, who were just my kind of mailing list of readers, were all science dorks too so I was really writing it for them.

Advantage of researching the science

One thing it did was it added plot, which was really handy. Just by sitting down and doing the math and checking everything, I discovered problems for Mark [the stranded astronaut in the story] to run into that I never would have thought of just creatively. For instance, when I was saying like, "OK, what would it take for him to grow his potatoes on Mars? OK, well he needs this, he needs this, he needs this." And I realized he wouldn't have anywhere near enough water, so that's where I came up with the whole subplot where he turns the fuel into water, and that was fun. It was exciting. I never would have even thought about him not having enough water if I hadn't done the math on the science.

Finding scientific information for his story

At the time I wrote "The Martian," I didn't know anyone in aerospace at all. I do now, but back then, I didn't know anyone so it was all just Google searches. That plus just a lifetime of being a space dork, you know? People are knowledgeable at their hobbies.

Goals as a science fiction writer

[To] entertain, always. Everything I write, I just want people to have fun when they're reading it. I don't have any agenda beyond that. I'm glad that "The Martian" was useful as an educational tool, and that kind of makes me warm and happy inside, but that wasn't my objective when I wrote it. I'm never trying to change anyone's mind on anything or preach any concepts or anything like that. There's never a deeper meaning or a moral. I just want people to read the book and go, "That was cool."

There's never a deeper meaning or a moral. I just want people to read the book and go, "That was cool."

Hollywood ending of "The Martian" movie

I thought it was good. I thought it was great. I mean yeah, they differed on the ending a bit but they had to make it more dramatic. In my ending it was really more about ... they very, very carefully planned out what they're gonna do and then they did it and there were a few complications but for the most part it worked, and that's a very kind of NASA way of doing this. But for a Hollywood ending you need a little more excitement. They send Lewis out to go rescue him instead of Beck, the EVA specialist because you've got Jessica Chastain in your cast, you want her to do more cool stuff if possible. Then having him come back to Earth, I think it's important. In a movie, it's easy to just cut forward in time eight months to then, "Oh yeah, now they're back on Earth." But in a book, it really was disconcerting. I did originally have an ending that showed them back on Earth, but it's really disconcerting to have, the very last scene of the book there's like this huge time cut, and then the last scene of the book and then it's over. It just didn't work, so I ended it right after he gets rescued, but yeah, I really liked the ending of the film.

A spaceship that can reach Mars

I honestly believe, and I know this is a political hurdle to overcome, I think really you need to have reactors. You need to have nuclear reactors to power your space vessel. I just don't see a solar-powered ion drive having enough beef to it. Just the total area of solar power that you'd need is too much, but a nuclear reactor is the most weight-efficient method of bringing a whole butt load of energy with you. Both the Soviets and the U.S. space agency back during the space race worked on it and even put reactors into space, so it's not unprecedented. You have to go to NASA and NASA has to go to Congress and everybody has to agree like, "OK, we're gonna put a nuclear reactor in space." And for a lot of people the word "nuclear" is just horrifying. ★

DARPA

Game changer

The U.S. Navy wants to do from the sea what the U.S. Air Force can do from land with its MQ-1 Predator and MQ-9 Reaper unmanned planes: Spy on targets for many hours, and when the time is right, command the planes to strike them. The barrier to such a plane has always been the limited room on vessels for takeoffs and landings. Henry Canaday looks at plans for a demonstrator that could solve this DARPA-hard problem.

BY HENRY CANADAY | htcanaday@aol.com

The Navy's catapult-launched ScanEagle drones can see beyond the horizon, but they're too small to carry Hellfire missiles or guided bombs. The unmanned Fire Scout helicopters need only a small deck for takeoffs and landings, but generating lift solely with rotors means burning fuel faster than a fixed-wing plane would.

For the Navy, the missing piece of the unmanned puzzle is a MALE, or medium-altitude long-endurance unmanned aircraft, that could fly from its frigates and destroyers. DARPA and the Office of Naval Research set out in 2013 to find a possible design for such a craft. They put DARPA in charge of development, divided funding responsibility equally and named the program the Tactically Exploited Reconnaissance Node, although they now prefer to call the program simply Tern. In 2014, they settled on a concept proposed by Northrop Grumman, the Fire Scout builder, for a flying-wing aircraft that would be stowed in pairs on their tails inside the hangar of a destroyer or frigate.

Concept of operations

As "tail-sitters," the aircraft would take off vertically powered by counter-rotating rotors on their noses and then transition to fixed-wing flight. If the Navy decides to buy them, two Tern airframes would form a single system that would maintain continuous surveillance for 10 days. When one aircraft needed to land, the other would relieve it on station. Tern needs to fly at about 15,000 feet and orbit 600 nautical miles from the ship while carrying 500 pounds [227 kilograms] of sensors, data links for communication and under-wing weapons. The aircraft would keep watch for missiles that might be launched from many hundreds of nautical miles away.

That's how things could work if a series of at-sea flight tests goes well in 2018. Northrop Grumman is building two demonstration versions of Tern and completing development of the software that will manage their flights.

Developers knew from the start they were entering "uncharted territory," says DARPA's Brad Tousley. "No one has flown a large unmanned tail-sitter before," he says in an article on the agency's website.

The two demonstrators must fit in the same size ship hangar that today carries a single MH-60 helicopter. In the test flights, Tern must take off from and return autonomously to the helicopter deck of a small ship, even in rough seas.

"This is revolutionary, we had never put such a level of performance on a small ship. That made it a hard problem, a DARPA problem," says Bob August, who manages Tern for Northrop Grumman.

Narrowing the field

DARPA initially looked at several possible configurations, including pure fixed-wing aircraft. This approach was ruled out early on because the fixed-wing designs were too large, and the required accessory equipment to launch and recover them would have been complex and substantial. "Aircraft size and geometry were strongly influenced by the size of existing MH-60 hangars," explains DARPA Tern Manager Graham Drozeski. DARPA converted the fixed-wing idea into another program, SideArm, a self-contained, portable apparatus to launch and retrieve other unmanned aircraft from trucks, ships and fixed bases.

The space restrictions urged a rotorcraft, but long endurance urged the efficiency of fixed-wing flight. DARPA decided it needed an aircraft that could transition from vertical flight to fixed wing and back. In principle, tilt-rotor, tilt-wing, vectored thrust, tail-sitting and ducted fan concepts might meet this requirement.

Northrop Grumman's tail-sitter approach seemed the most practical. "The tail-sitter was sim-

◀ DARPA plans to build two full-scale demonstrators of a medium-altitude long-endurance unmanned aircraft called Tern.

▼ **Technicians assemble** a Tern airframe at Scaled Composites in Mojave, California.

Scaled Composites

U.S. Navy

▲ **Northrop Grumman** is adapting autonomy software from its unmanned Fire Scout helicopter for Tern.

ple in mechanics and system integration, and simple is generally good," August says. Two Terns, with wings folded, could fit in the small hangar.

Flying a tail-sitter

With the basic design settled, challenges in control, propulsion and software remained. Tail-sitting aircraft had been developed and abandoned before. The Ryan X-13 Vertijet flown by the U.S. Air Force in the 1950s illustrated the inability of a pilot to see well during landing or takeoff, something that's not a problem for the unmanned Tern. Vertijet was of course powered by a jet engine, unlike the rotor-propelled Tern.

What Tern does require are precise controls to take off and land on a small ship in the tumult of the sea. "The dynamic interface of flight deck and air wakes behind ships in elevated sea states drove configuration and control designs," Drozeski says. Specifically, Tern must take off and land even in sea state 3 and ideally up to sea state 5, which means waves of up to 4 meters.

Northrop Grumman settled on two coaxial rotors, one rotating clockwise, the other counter-clockwise. This way, the demonstrators won't need a tail rotor to counter torque by generating a yawing moment. The concept takes advantage of the best attributes of rotors and propellers. Like all rotors, Tern's are hinged at their roots. They will change angles collectively, like solid propellers, when necessary for maximum vertical lift, and individually to generate the exact pitch and roll needed to keep the aircraft stable during vertical flight and to change angles of attack in the transition to horizontal flight. Tern moves steadily through these angles rather than spending time at different angles, as the V-22 Osprey tilt-rotor does. Once in horizontal cruise flight, the rotors change angles only collectively, like propellers, so air will flow over the wing and flight-control surfaces, which now steer the plane.

Testing

Northrop Grumman engineers spent many hours running computational fluid dynamics models to solve the aerodynamic problem and design the rotors, the wing and power requirements for the demonstrators. A special concern was the need to design rotors that could operate in horizontal and vertical modes. Designers of the V-22 Osprey achieved that, but no one has managed it with any previous tail-sitters, Drozeski says.

The demonstrators must generate a thrust-to-weight ratio greater than 1 in hover and substantially less than 1 in cruise. To gain long endurance, cruise efficiency becomes much more important than speed. This efficiency is in turn a function of airframe efficiency — primarily lift to drag engine efficiency — at low throttle and fuel weight.

DARPA and Northrop Grumman selected carbon fiber reinforced polymer for the airframes being made by the company's subsidiary Scaled Composites. August says this choice of material was driven mostly by the need to rapidly prototype the demonstrators.

For propulsion, Northrop Grumman chose to modify the General Electric T700 turboshaft engine, the same kind of engine that powers the Navy's MH-60 Seahawk helicopters. August says T700 had the right power and the Navy knew the engine well, but that some changes had to be made for the Tern application.

The T700 is positioned horizontally when supplying power to the vertical shaft of the Seahawk, but on Tern it will be tilted vertically during takeoff and landing. GE had to modify the engine to ensure that both engine and gearbox would be lubricated in this vertical position.

Turboshaft engines like the T700 also have gears and a gearbox between engines and power shaft. New gears and a new gearbox had to be designed and built for Tern. Northrop Grumman needed to devise gearing to give the T700 enough power at full throttle for vertical climb, and also a throttle-back mode that would achieve efficiency for cruise. And it had to design a new gearbox that would fit into demonstrators' wings.

For the autonomous control, Northrop Grumman is adapting autonomy software from the firm's Fire Scouts. The autonomy is key, because the Navy won't add crew for the Tern beyond the number required to maintain and operate two Seahawks aboard. If operational versions of Tern are built, crew members would move the planes in and out of the ship's hangar and then an operator would initiate the launch sequence and give the aircraft its mission plan from a control station either onboard the ship or remotely. The aircraft would fly the mission and autonomously return and land on the ship, unless the operator decides to override this autonomous operation for some reason.

The Fire Scout experience and computer modeling were helpful in developing the flight management software for the aircraft, but Northrop Grumman also needed wind-tunnel tests to document how the aircraft will behave in flight.

So in 2016 DARPA tested scale models of Tern in the National Full-scale Aerodynamic Complex at NASA's Ames Research Center in California. The agency will do more wind-tunnel tests of models in mid-2017 to generate data describing how the aircraft reacts to different airflows. "We need to see the lift and drag at different speeds, attitudes and levels of thrust," Drozeski explains.

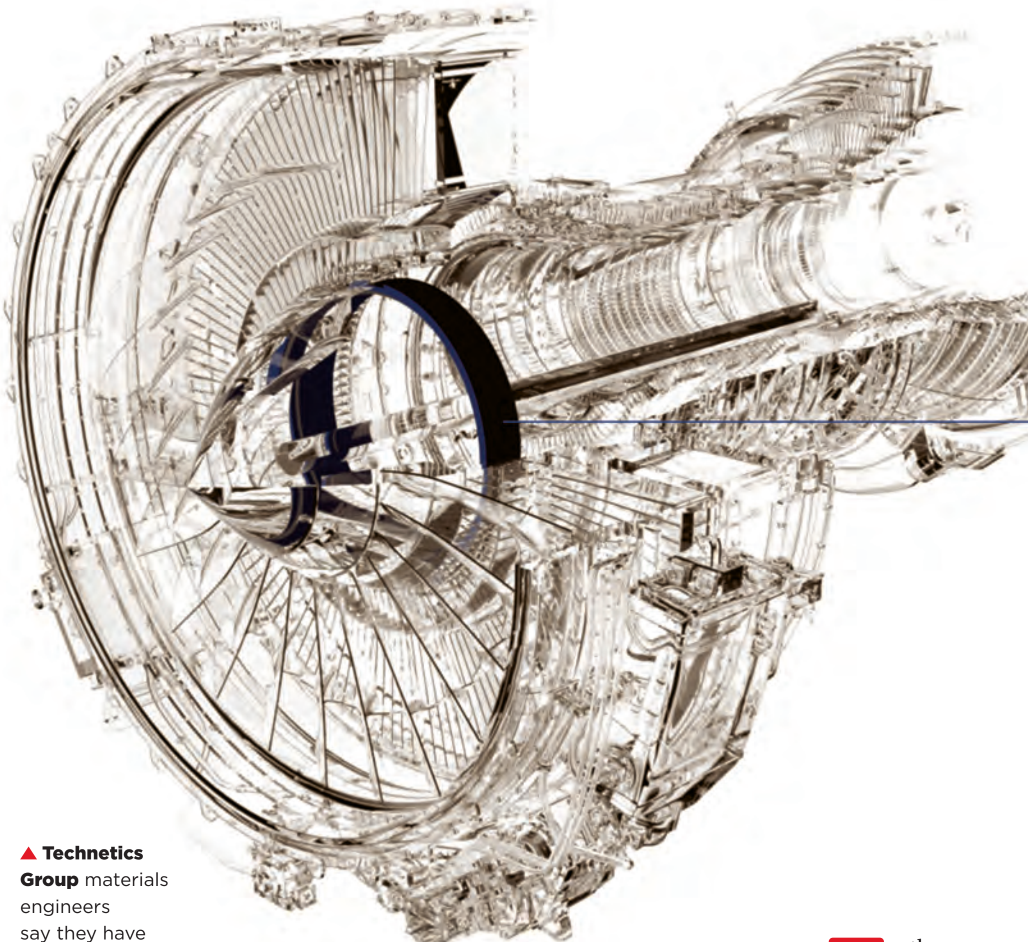
Meanwhile, Northrop Grumman this year will put the integrated propulsion system, including the T700-variant engine, through its paces in ground tests at full and lesser power and at different tilt angles. These tests will be aimed at validating engine and gearbox performance at key operating angles.

These wind tunnel and engine tests should set up the demonstrators for the planned series of flight tests in 2018 in which the demonstrators will take off, execute their mission and return to a ship.

Drozeski expects any production version will look a lot like the demonstrators. But the Navy will make the final tradeoffs between cost and performance on, for example, the materials used for the airframe. ★

FACTOID

In the 1950s, the Air Force tested the X-13 Vertijet, a vertical takeoff and landing jet. According to the Smithsonian National Air and Space Museum, the U.S. was interested in developing an aircraft that could be based at a small operating site rather than a large base that was more vulnerable to missiles and nuclear weapons.



▲ **Technetics Group** materials engineers say they have designed a better compressor seal for jet engines.

Protecting turbine blades

The compressor seals in the outer gas path inside jet engines have a tough job. They have to keep hot gases from escaping without damaging or wearing down the spinning turbine blades. Principal materials engineer Elaine Motyka of Technetics Group of Deland, Florida, describes the company's endeavor to develop a better seal starting with a new material.

BY ELAINE MOTYKA | elaine.motyka@technetics.com

In the compressor section of a jet engine, abradable seals fill the gap between the turbine blade tips and the engine casing. During thousands of cycles between flight idle and high power, these seals perform the critical function of mitigating the leakage of air and gases that would rob the engine of propulsion and payload efficiency. A seal must be replaced once it decomposes too much due to erosion, impact damage, or high temperature oxidation.

In 2013, Technetics Group set out to make a new seal material and ultimately a new seal that would last longer and impart less wear on turbine blades compared to seals made of conventional materials, including today's widely used fiber-metals. In 2016 we completed rub tests on a new metal matrix composite, or MMC, seal material. This advanced abradable material, which we've trademarked as Bladesafe, is a proprietary blend of metal alloys and solid lubricating ceramic and we are ready to manufacture seals from it. Our tests were encouraging and we are confident that turbine manufacturers will soon want to conduct engine testing with seals made of this new advanced abradable material.

Getting to this point required addressing some fascinating materials engineering challenges. Today, with blade-tip surface speeds sometimes exceeding 300 meters per second, rub events between a seal and the surface tips are more likely to damage the blades, even though the seals are abradable to absorb the energy of the impacts. Hard coatings applied to the blade tips are often a method used to protect them from wear. This is not an optimal solution, as the coatings add cost, weight and have the potential to delaminate.

An optimum seal would allow rub events without significant damage to the blade and without requiring a tip coating. The seal would resist erosion, oxidation and air leakage while maintaining enough thickness to reduce the blade-casing gap.

Tradeoffs

Seals have typically been attached to the inner surface of the engine casing or a backing plate in one of several methods, depending on the kind of engine. Layers of metal alloy or honeycomb materials can be heat brazed onto the surface. Fiber-metal seals, where alloy fibers are strengthened by diffusion bonding or sintering, can also be attached by vacuum brazing. Composite coatings can be deposited by thermal spray methods onto the interior of the casing.

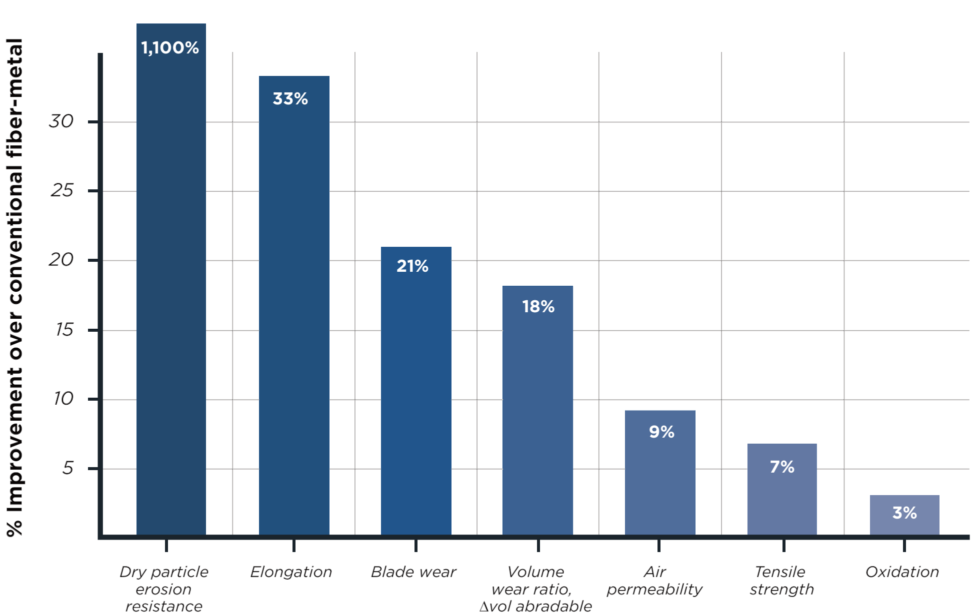
Each of these current materials and methods comes with tradeoffs that Bladesafe avoids. Fiber-metal causes less damage to turbine blades than honeycomb, but it is more permeable to air and gases and it has very low erosion resistance. Thermal spray coatings are more gas-tight and erosion resistant than fiber-metals, but they are so damaging to the titanium blades that hard coatings must be applied to them for wear protection. In addition, thermal spray coatings are limited in applied thickness, whereas honeycomb and fiber-metal can be applied up to several millimeters, allowing for tighter clearances.

We began our MMC project with a special understanding of aircraft turbine seals, fiber metals and sintering. Technetics has been manufacturing fiber-metal abradable seal material for over 40 years with more than 1 billion flying hours on numerous engines. This material is fabricated from fine metal fibers that have an effective diameter of 10-20 microns and a length-to-diameter ratio of 60-90:1. The fibers are typically derived from various metals depending on the specific needs of the turbine engine application. The fiber is "felted" into sheet form and subjected to a proprietary sintering cycle in which bonds form at points of contact between the fibers. The sintered sheet is then rolled to the required thickness and density and cut to size. The final product is a strip of fiber-metal material that is ready to be brazed or mechanically attached into the case or onto a backing plate.

Fiber-metal material is porous by nature with an apparent density, typically applied at 15 to 30 percent of the wrought material. We can design the material

Advanced abradable material vs. conventional fiber-metal

Technetics Group says its Bladesafe material surpassed the performance of conventional fiber-metal in tests of seven attributes.



Source: Technetics Group

to have an ultimate tensile strength of 500 to 3,000 psi, depending on the seal requirement. UTS can be set independently of other physical properties via the manufacturing process. This flexibility is important because UTS largely determines the abradability and erosion properties of the material. This ability to "tune" the abradability and erosion properties gives the designer flexibility to select the optimum material for each application. The new MMC material maintains this designer flexibility.

In rub events where the blade tip speed is relatively low (less than 300 meters per second), conventional fiber-metal, including ours, does not cause significant wear to titanium blades but it has relatively low erosion resistance to particles in the gas path. In a rub event where the tip speed is high (300 m/s or greater), highly porous fiber-metals eventually compact and overheat from friction forces, damaging the blades and causing localized melting or even failure of the seal.

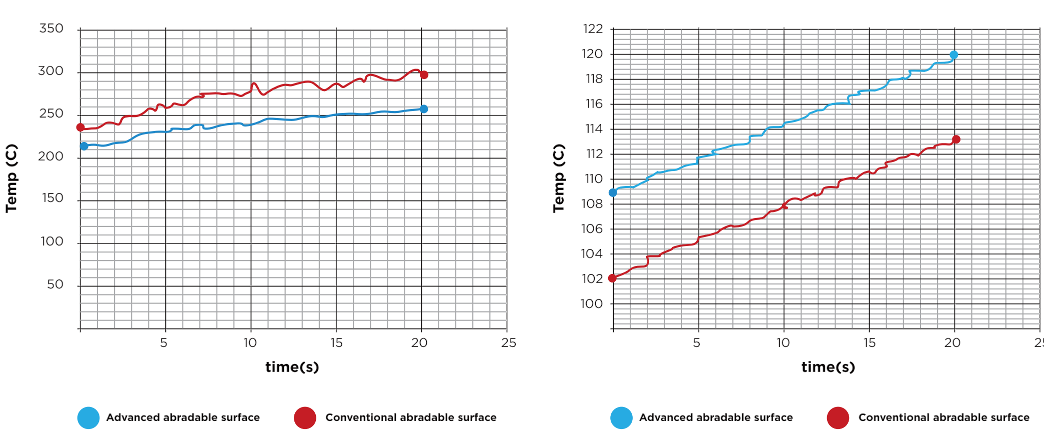
Our MMC seal material addresses most of these tradeoffs and shortcomings. The composition and structure of the MMC mitigate compaction and friction while they also strengthen the material against erosive particles. The MMC has increased apparent density 30 to 60 percent, which improves permeability. Like conventional fiber-metal seals, the MMC can still be attached to the interior of the casing using vacuum brazing methods. We have engineered the MMC with unique structure and properties to cause reduced wear of the blade as well as to increase the erosion resistance of the seal itself at higher speeds and temperatures. The unique material of the new seal provides a sacrificial abradable response that is better than conventional fiber-metal to a blade incursion while maintaining resistance to erosive particles similar to thermal spray coatings.

Tests

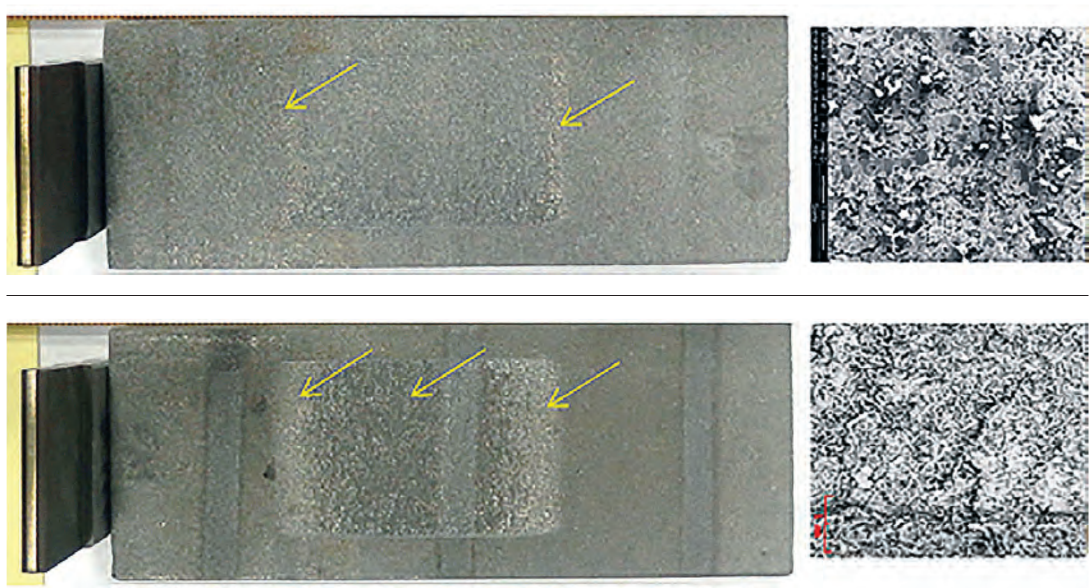
We know these facts from the series of rub tests we conducted. Using a high-speed abradable test rig at another organization, our engineers conducted iterative testing of several developmental concept materials. The rig was comprised of test blades mounted on a rotating disc that can create blade speeds up to 500 m/s. The MMC abradable material was brazed to a shroud or backing plate to simulate the casing. This sample was moved into the rotating blade at controlled incursion rates. Wear of the blade and the seal material was documented. Initial testing focused on the same titanium alloy found in most turbine blades, Ti6A14V. We ran the same tests on a sample of our conventional low-density fiber-metal material. Compared to fiber-metal, the advanced abradable material has higher apparent density, increased tensile and yield strengths, reduced percent-elongation (or ductility), increased dry particle erosion resistance, reduced air permeability and improved oxidation resistance at higher temperatures.

Better heat conduction

These temperatures indicate that the surface of the advanced abradable material stayed cooler in tests while the shroud (the metal plate that holds the abradable) was hotter, showing that the advanced abradable does a better job of conducting heat away from the surface.



Source: Technetics Group



The yellow arrows on the iPhone photos (near right) of the abradable materials point to less adhesive wear on the advanced material (top) compared to the conventional. The scanning electron microscope images (far right) show wear scars on the test images.

Technetics Group

Under the high-speed, moderate-incursion blade rub conditions, the advanced abradable material resists compaction and densification, interrupting the damaging sequence of events typical of conventional porous fiber-metal abradable materials. In addition to resisting compaction and densification of the surface, the advanced abradable material has been engineered with reduced ductility to allow for localized micro-fracture under blade contact, resulting in a better sacrificial wear response compared to fiber-metal. The advanced abradable material also incorporates advanced high-temperature solid lubricant ceramic material so that the seal acts as its own lubricant to reduce the friction coefficient where blade contact does occur. The degree of surface densification, increased contact area, and heat generation normally observed with fiber-metal is significantly reduced in the advanced abradable material.

Under rub conditions with uncoated Ti blades at high surface speed (410 m/s) and moderate incursion rate (50 microns/s), the combination of high strength and reduced ductility allows the advanced abradable material to wear by mechanisms, such as cutting, that are known to be less damaging to blades. We know from experience that cutting as a wear mechanism requires less energy for material removal compared to adhesive wear and rupture mechanisms. When adhesive wear mechanisms dominate, Ti from the blade adheres to the seal material and the alloy from the seal material adheres to the blade, creating rough surfaces with high friction forces and significant localized heating. The heating weakens both the seal and the blade tip, accelerating wear of both the blade and the seal and creating the risk of cracking of both.

The benefit of a wear mechanism where cutting dominates and compaction of the surface is reduced is that less heat is generated at the rub surface. Consequently, the denser and stronger advanced abradable material can have a rub event with the Ti blade without increasing the severity of the blade wear.

In addition to wear of the blade and the abradable material, temperatures were measured of the abradable surface and of the backside of the shroud to which it was brazed. The temperatures are consistent with the abradability observations; that is, the denser MMC had lower surface temperature due to more favorable cutting wear mechanisms. The backside of the shroud (or casing) had higher temperature as the denser material had better heat conduction.

Compared to thermal spray coatings, the advanced abradable seal material has a thickness advantage. It can be made in sheets as thick as 10 mm, whereas thermal spray is typically applied to the interior of a casing 2-3 mm thick. Because of the greater thickness, the turbine engine designer can accept deeper blade incursions, such as those from greater surge or out-of-round conditions, and have a minimal initial gap between blade tip and casing for maximum compressor efficiency.

All told, we found that under high-speed uncoated Ti6Al4V blade incursion, compared to conventional fiber-metal, less heat is generated at the abradable surface, less blade wear occurs, less abradable seal wear occurs, and wear mechanisms involving blade-damaging adhesive transfer are reduced. The Bladesafe advanced abradable material also has a higher dry particle erosion resistance and lower air permeability. It is denser and stronger than fiber-metal and has a lower oxidation rate at 650 degrees Celsius [1,200 Fahrenheit], the gas path temperature inside typical aircraft engine compressors. ★

Elaine Motyka

is the principal materials engineer at Technetics Group in Deland, Florida. She is the technical leader of the team that developed a new metal matrix composite seal material that is now ready to be marketed to customers. She holds a Bachelor of Science degree in mechanical engineering from Worcester Polytechnic Institute in Massachusetts and a Master of Science degree in materials engineering from Rensselaer Polytechnic Institute in Troy, New York.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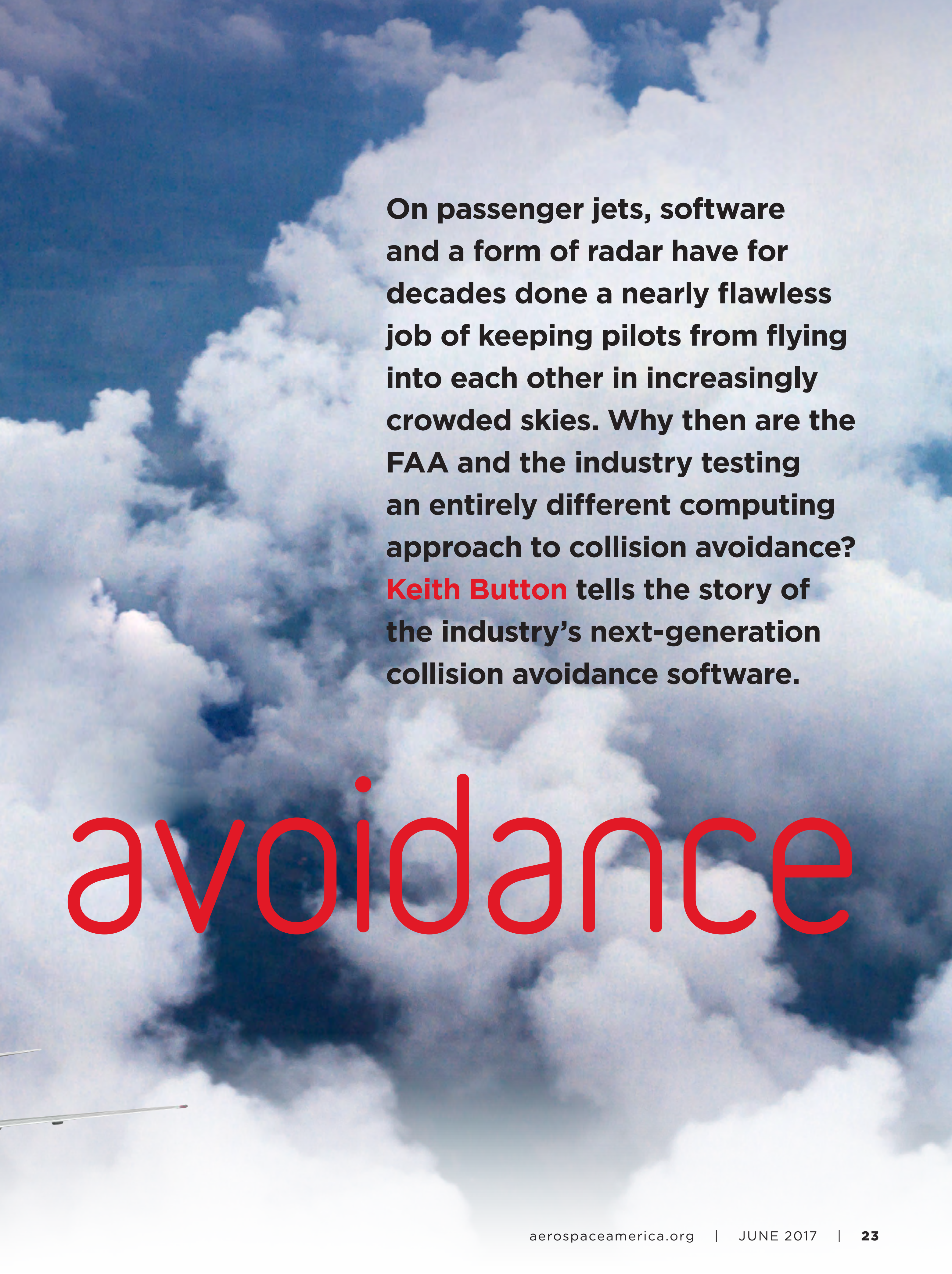
SMARTER Collision



On passenger jets, software and a form of radar have for decades done a nearly flawless job of keeping pilots from flying into each other in increasingly crowded skies. Why then are the FAA and the industry testing an entirely different computing approach to collision avoidance? Keith Button tells the story of the industry's next-generation collision avoidance software.

avoidance

On the morning of June 30, 1956, two airliners embarked on flights that would shape the next 60 years of air traffic safety measures. The planes departed from Los Angeles International Airport within three minutes of each other, one headed for Chicago and the other for Kansas City, Missouri. Their paths converged 90 minutes later, at 21,000 feet over the Grand Canyon in Arizona. The left wing of the Chicago-bound United Airlines Douglas DC-7 smashed into the tail of the Trans World Airlines Lockheed L-1049 Constellation, shearing off the tail of the Constellation and badly damaging the DC-7. Perhaps most terrifyingly, crash investigators reported that it was possible that the DC-7's pilots saw the pending collision and attempted a last-second maneuver. The angle of impact of the DC-7 on the Constellation, as deduced from the wreckage, suggested that the DC-7 was rolled to the right and pitched down relative to the Constellation. The collision killed all 128 aboard the two planes. At the time, it was the worst commercial air disaster in history.

The public outcry from the Grand Canyon air disaster spurred Congress to create the FAA in 1958. Among the agency's first actions was to study potential collision avoidance systems that planes might carry to alert pilots. By 1981, researchers had developed the Traffic Collision Avoidance System, or TCAS, a box of electronics and software that transmits a radar signal that interrogates transponders on nearby planes. The responding radio signals contain the altitudes of the surrounding planes, and distance is calculated from the fractions of a second it takes for them to arrive. If the TCAS software on one plane judges another as too close, an automated voice sounds "traffic, traffic!" After a midair collision in 1986 that killed 79, Congress required all large aircraft in the U.S. to carry TCAS. Since 1993, Congress has required all planes with 30 or more passengers to carry TCAS 2, which issues coordinated collision resolution advisories to each pilot such as "climb, climb!" or "descend, descend!" or "level off, level off!"

Now, computer scientists and aerospace engineers are finishing development and testing of a new onboard alert software developed under the guidance of the industry's RTCA association, founded in 1935 as the Radio Technical Commission for Aeronautics. The new software is called the Airborne Collision Avoidance System Xa, or ACAS Xa for short (The "a" stands for active surveillance.). It's supposed to outperform TCAS 2 on safety and reduce unneeded alerts by adopting a more modern computing approach and by taking advantage of GPS position reports in the messages sent from the Automatic Dependent Surveillance-Broadcast transponders that planes are starting to carry. The work is funded by the FAA, the European Organisation for Civil Aviation Equipment and RTCA.

The stakes will be high as ACAS Xa begins to replace TCAS 2. If market projections are accurate, air traffic will continue to grow. In the year of the Grand Canyon disaster, 45.9 million passengers flew on commercial airlines. That number climbed to 3.8 billion as of 2016 and is predicted to explode to 7.2 billion by 2035, according to the International Air Transport Association.

Fresh thinking

ACAS Xa and TCAS 2 take two very different computational approaches to the problem of calculating when to sound an automated voice alert to the pilot. The TCAS 2 software runs through a long series of "if-then" statements to determine whether to issue an alert. In contrast to this conventional computing method, developers of ACAS Xa at the Johns Hopkins University Applied Physics Laboratory in Maryland and MIT Lincoln Laboratory outside Boston capitalized on concepts within the field of artificial intelligence. The software directs the computer to make decisions based on probability distributions for possible outcomes at each step in a time sequence, because the exact circumstances for those decisions can be only partially known ahead of time.

The FAA began flight tests of ACAS Xa in March with a goal of validating the results of years of modeling and simulation. Developers don't expect problems. Dating back to 2011, ACAS Xa software has run through millions of simulated encounters and 180,000 real-life potential collision situations as recorded by radar stations near busy airports. The testing and simulation results are analyzed by industry groups representing pilots, air traffic controllers, avionics manufacturers and others. Developers then tweak the ACAS Xa code based on this feedback. When the ACAS Xa code is finalized, an RTCA committee will recommend it as a standard for the FAA and regulators in Europe and elsewhere to possibly adopt by 2020.

For the FAA, shifting to ACAS Xa is about preparing for the future more than fixing any serious flaws in TCAS 2. There has never been a collision in U.S. airspace involving an airplane equipped with TCAS 2, and internationally, accidents and near misses have been rare.

Job number one for the developers was to make sure that ACAS Xa and TCAS 2 software would be interchangeable, so that transitioning to ACAS Xa

▲ **The tail section** of a Lockheed L-1049 Super Constellation lies in the Grand Canyon after colliding with a United Airlines Douglas DC-7 in 1956. Public concern about the accident led to the creation of the FAA.

National Park Service

SAFETY IMPROVEMENT

The FAA typically sets safety standards for airplane components as measured in acceptable failure rates, such as 1 catastrophic failure in 1 billion hours of flight time, or 1 in 10 million hours. But for collision avoidance systems, the FAA measures relative risk. For the best version of TCAS 2, if both airplanes are equipped with the system, their risk of colliding is 97 percent less than if they didn't have the system. For ACAS Xa, the relative risk is about 98.5 percent less than not having the system, or 40 percent better than TCAS 2.

would amount to a software upgrade by an avionics vendor. TCAS 2 and ACAS Xa run on the same components: a computer, typically weighing 5 to 9 kilograms; plus antennas; transponders; a control panel; and a visual display. For the crew, the experience will be the same in terms of the alerts. The initial "traffic, traffic!" alert prompts the pilot to look out the window to try to visually spot and avoid the other airplane. With both software options, an imminent collision, say within 15 to 35 seconds, prompts a computer voice to sound maneuver alerts, and the cockpit display tells the pilot at what rate to climb or descend. The altitude-encoded transponders on both aircraft communicate to coordinate the maneuver, so that if one climbs, the other descends.

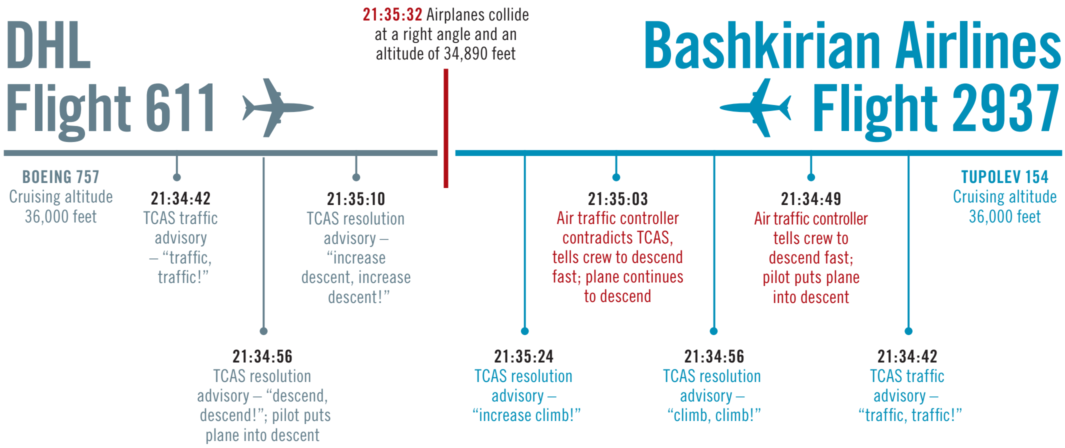
When the planes are no longer in danger of hitting each other, the pilots hear "clear of conflict." The collision avoidance maneuvers are always vertical; the systems do not tell pilots to turn left or right. Separately, FAA-funded developers of a version of ACAS for unmanned aircraft, dubbed ACAS Xu, are trying to build a computer program that can order horizontal collision avoidance maneuvers.

Seeing the future

Developers of ACAS Xa faced two main challenges: As precise as ADS-B is, the future trajectories of airplanes remain notoriously hard to predict mainly because of the range of navigation decisions that pilots of two planes might make. Secondly, ACAS Xa relies on transponders — both the altitude-encoded transponders of the TCAS 2 systems and the new ADS-B transponders — that provide data that isn't always accurate. To solve those challenges, ACAS Xa attacks uncertainties with probability distributions.

Anatomy of a collision

Bashkirian Airlines Flight 2937 and DHL Flight 611 collided in 2002, killing 71 people. The aircraft were equipped with TCAS 2. Among the contributing factors, investigators found that the Bashkirian Airlines cockpit crew followed air traffic controller instructions rather than TCAS 2 advisories.



Source: German Federal Bureau of Aircraft Accidents Investigation

Note: Timeline is not to scale

"One of the things that ACAS leverages is that nothing that is unknown in the world is a point anymore," says Josh Silbermann, project manager for ACAS and TCAS at the Applied Physics Lab. Unknowns are treated by the computer code as a "distribution" of possibilities. "We think [a plane is] going to be here, but it might be over there; there's less of a chance it might be over there."

TCAS 2 and ACAS Xa each receive updated transponder data every second, but aside from that, they take two different pathways of logic to predict the future. TCAS 2 starts out by predicting that two planes will continue flying straight on their current trajectories. Then it follows a series of if-then statements to expand its alerting criteria to account for the possibility that the straight-line predictions might be wrong. By contrast, ACAS Xa assumes that the current courses of the planes could change in a few seconds. It calculates every possible future pathway for the planes for the time period between the present and the time of possible collision. Then, for each of those pathways, it calculates the probability of the plane taking that pathway. It predicts the future pathways for every one-second increment moving forward in time. For example, starting from an airplane's current trajectory, ACAS Xa might predict that one second into the future the airplane's most likely state would be to continue flying straight with no acceleration. The second-most-likely state one second into the future might be flying in a straight line with a small acceleration and flying in a straight line with a small deceleration. And the third-most-likely state one second in the future might be a straight line with slightly larger accelerations or decelerations. From each possible state one second in the future, ACAS Xa calculates every possible state two seconds in the future, and the probability for each of those states. It calculates this for every one second increment into the future, figuring every possible future pathway and its probability within the given time.

SOFTWARE SECRETS

The TCAS 2 collision avoidance software follows a long series of "if-then" statements to determine whether or not to issue a collision warning. If written out, these rules would run for more than 1,000 pages.

ACAS Xa calculates its future pathways inside a bubble measuring 40 seconds from a possible collision. All of the calculations are completed ahead of time and loaded into the ACAS Xa software on the onboard computers. In flight, once two planes are 40 seconds away, ACAS Xa consults this giant lookup table containing 4.5 million possible future states between the present and the possible collision, calculated horizontally. Each state is defined in five dimensions: the vertical separation of the aircraft, the vertical rate of climbing or descent for the host aircraft, the vertical rate of climbing or descent for the other aircraft, the time until loss of horizontal separation and the current alert for the host aircraft — whether it's being told to climb, for example. Each

"Even if you had perfect sensor information, you wouldn't be able to perfectly predict where all the aircraft will be in the future." — **Mykel Kochenderfer**, Stanford University

dimension is described in 10 to 60 ways.

The ACAS Xa giant look-up table also defines the correct alert action for every possible state in the 40-second bubble around a potential collision. The software has determined the optimal alert actions ahead of time, before the software is loaded into the onboard computer. It calculates this by starting at the end state, which is when the distance measured horizontally between the airplanes would be zero, also known as the closest point of approach. The closest point of approach isn't necessarily a collision; it's a stack of points along a vertical line where the horizontal distance to the other aircraft is zero. The software calculates the optimal action the pilot should take at the end state. Even if that end state is zero horizontal distance and zero vertical distance between the planes — essentially a collision — the software's logic never sees giving up as an option; it always sees a mathematically optimal action to take. Then, backing up one second, it calculates every possible state that would lead to that end state. And for each of those backed-up-one-second states, it calculates the optimal action the pilot should take to avoid the end state.

The software repeats the process, backing up one second at a time, until it has covered every possible state — tens of millions of them — in that 40-second bubble, as measured in the five dimensions. An algorithm compresses the number of states to 4.5 million by removing duplicates.

In flight, once ACAS Xa locates the current state in the giant table, it executes the predetermined action: alerting or not alerting, and telling the pilot the avoidance maneuver if warranted.

The alert or no-alert decision for each state is based on probability distributions that account for uncertainties, accounting for all possible outcomes and selecting the optimal decision, says Mykel Kochenderfer, a computer scientist and aerospace engineer at Stanford University who in 2008 created the concept that other researchers developed into ACAS Xa.

"The computer reasons about all of these low-probability events in a way that humans are not quite as skilled at doing," he says. "We as humans like to think about the world evolving largely deterministically. So, we predict the aircraft flying straight. The computers, however, can take into account the probability that they're flying straight — or they're turning, or climbing — as the next step."

The ACAS Xa approach of projecting the future as a range of probability-weighted possibilities is supposed to do a better job of accommodating the possibility that transponder data could be inaccurate.

"It's fairly difficult for a human engineer to write down rules that will accommodate the spectrum of sensor error," Kochenderfer says. "Even if you had perfect sensor information, you wouldn't be able to perfectly predict where all the aircraft will be in the future."

An example of the sensor error problem: Mode C transponders, typically flown on smaller aircraft, report altitude to the nearest 100 feet, while Mode S transponders typical for larger airplanes report altitude to the nearest 25 feet. So two airplanes equipped with Mode C transponders shown as flying within 200 vertical feet of each other might actually be flying with 150 to 250 feet of vertical separation. Even with altitude readings rounded off to the nearest 25 feet, a calculated climb or descent rate based on those readings could differ considerably from the actual rate.

RIGOROUS TESTING

The FAA is testing the ACAS Xa next-generation collision avoidance software on a range of aircraft, including the Learjet 60, Bombardier Global Express, Boeing 707, Gulfstream 4, Model 90 King Air, Boeing 757, Convair CV-580, Dassault Falcon 900 and HU-25 Falcon. The planes are flying out of Atlantic City, New Jersey; MIT Lincoln Laboratory in Massachusetts; Phoenix and various FAA Flight Inspection Services locations.

Changing the rules

ACAS Xa also avoids what developers say is another major drawback of TCAS 2, which is that changing its rules for making alerts can be incredibly complicated. Altering any of the vast number of if-then rules in the TCAS 2 programming logic risks unintended consequences. Changing one rule can cause a ripple effect that forces programmers to make other changes in the system's logic. Regulators then require extensive modeling and testing to make sure no unintended consequences are missed. This means that even relatively simple changes to TCAS 2 can takes years to implement.

A case in point was the fallout from the 2002 midair collision over Germany between a Tupolev Tu-154 passenger plane flown by Bashkirian Airlines and a Boeing 757 cargo plane flown by DHL. The incident exposed a dangerous flaw in the TCAS 2 logic and is the subject of "Aftermath," an Arnold Schwarzenegger movie released in April.

Solving the trust issue for neural nets

The FAA is funding research into how neural networks, a form of artificial intelligence, might someday improve collision avoidance logic.

These computational models mimic the layers of neurons in the human brain. The artificial versions are not nearly as complex as our brains, but like our brains, they learn to solve problems efficiently through repeated exposure to data.

Neural nets perform well at solving problems with many inputs, such as in facial or voice recognition, and they compactly represent a decision-making process, says Mykel Kochenderfer, a computer scientist and aerospace engineer at Stanford University. A 2016 study by Kochenderfer and other researchers found that applying neural net techniques to software in development for unmanned planes, called the Airborne Collision Avoidance System Xu, reduced the storage size of the ACAS Xu data look-up table by 1,000 times. This table contains millions of possible states that the aircraft could be in relative to other nearby planes, such as relative velocity and direction. The table also contains the optimal collision avoidance alert and maneuver, or no alert, for each of those states. Also, simulations showed the neural net table produced fewer collisions and near misses, fewer alerts and fewer alert reversals, such as when an airplane is told to climb and soon after told to descend. A paper describing the study, "Policy Compression for Aircraft Collision Avoidance Systems," written by Kochenderfer and Kyle Julian of Stanford, Jessica Lopez and Jeffrey Brush of Johns Hopkins University, and Michael Owen of MIT, was released at the Digital Avionics Systems Conference in 2016 in Sacramento, California.

A challenge of neural nets is that the logic can be difficult for humans to verify. Kochenderfer and other researchers at Stanford have created a tool that could potentially prove neural networks will perform as expected, even with unseen inputs. A neural net can have a large number of parameters, and the specific figures for each parameter can be impossible to independently verify. "If you look at one of the parameters, it might be 2.93726. And someone might say: 'Well, how do you know that's the right number?' And the answer is: 'Well, it just works,'" Kochenderfer explains. "There is some level of discomfort if you're going to be betting people's lives on particular numeric values that you can't justify directly."

In hopes of solving the problem, the researchers developed a tool called an automated theorem prover. It's described in "Reluplex: An Efficient SMT Solver for Verifying Deep Neural Networks," a paper by Kochenderfer, Guy Katz, Clark Barrett, David Dill and Kyle Julian, that was preprinted in February by the upcoming International Conference on Computer-Aided Verification.

Neural nets would have to prove that the logic performs in a repeatable, deterministic fashion, says Neal Suchy, the FAA's program manager for ACAS Xu and a version for passenger planes, called ACAS Xa.

"It's those corner cases, and vetting that whole logic space with a neural net that becomes very challenging," he says. "The concept is completely new in this kind of application for a regulatory body, so the scrutiny is a lot higher as a result."

Rolf Haid/picture-alliance/dpa/AP

With the two planes on a collision course, their TCAS 2 software coordinated a "resolution advisory" that instructed the Tupolev pilot to climb and the DHL pilot to descend. The trouble was, an air traffic controller had already told the Tupolev flight crew to descend, and the crew followed that advice rather than what they were hearing from their TCAS 2. Both planes continued to descend, and the resulting collision killed all 69 aboard the Tupolev and the two aboard the DHL plane.

Programmers set out to fix the TCAS 2 glitch that maintained a resolution advisory even when two

▲ **In 2002,** a Russian Tupolev passenger jet and a Boeing cargo jet collided over Ueberlingen, Germany, killing all aboard. Here, relatives of plane crash victims visit the site where a piece of the Tupolev fell.

planes continued on a collision course, because one of the planes did not comply with that advisory. It took nearly 15 years to prove that these relatively minor changes to its logic would be safe and win approval of regulators. The updated software is just now being rolled out.

Adjusting the logic for ACAS Xa will be far easier than for TCAS 2, says Neal Suchy, the FAA's program manager for ACAS Xa. Regulators can tweak the new collision avoidance system to accommodate changes much more quickly.

While ACAS Xa developers took several years to create the code that built the giant look-up table, it now takes only 10 to 15 minutes on a desktop PC to generate a new version of the table with modified parameters or conditions for advisories.

Programmers could make TCAS 2 account for anything that ACAS Xa does, if they wrote enough lines of code, Suchy says. "But that's a dangerous game in terms of software development, in terms of all the different metrics we have to do; the time it takes to actually get that system out. We're able to do these things much more efficiently and much faster and much better, with the ACAS X architecture." ★

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High speed air-breathing propulsion is becoming more prevalent. The standard approaches involve turbojets, scramjets, and turbine-based combined cycle systems. Emerging cycles include the Japanese ATREX engine and the air-breathing rocket engine, which rely on pre-cooling the air with heat exchangers. Additional emerging cycles include pressure gain cycles, Mass Injection Pre-Combustion Cooling, Oxy-Boost which injects oxygen during the cycle, and turbo-ramjets in which the air bypasses the turbojet at high speeds and the afterburner is treated as a ramjet. This course is designed to explore these cycles and bring a theoretical understanding of how to apply them and what performance advantages they might have.

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This short course is essential for all professionals specializing in chemical propulsion. The mechanisms associated with hybrid combustion and propulsion are diverse and affect our abilities to successfully advance and sustain the development of hybrid technology. The goal is to promote the science of hybrid rocketry that is safe enough to be used in both academia and the private sector.

Liquid Rocket Engines: Fundamentals, Green Propellants, and Emerging Technologies

This course will cover propulsion fundamentals and topics of interest in launch vehicle and spacecraft propulsion; propulsion system design and performance; green bipropellants and monopropellants and advances in additive manufacturing; and their implications toward emerging liquid rocket engines.

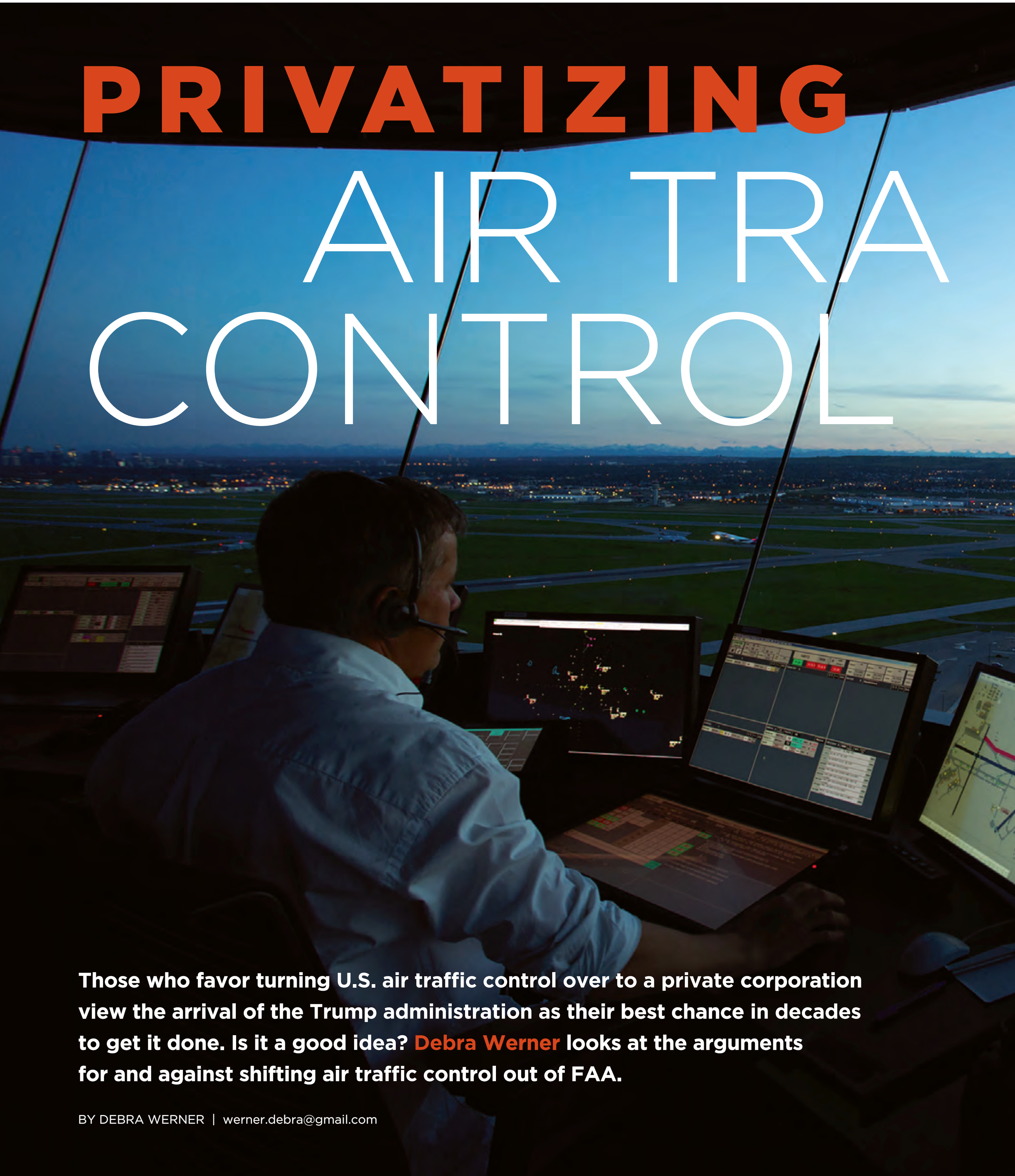
Missile Propulsion Design, Development, and System Engineering

In this course, a system-level, integrated method is provided for missile propulsion design, development, and system engineering.

Turbulence Modeling for Modern Industrial CFD *NEW!*

This course covers the fundamentals of turbulence modeling, beginning with the various equation systems and modeling strategies. Theoretical backgrounds are presented for second-moment closure and practical models are presented and demonstrated. Simplifications and alternative eddy-viscosity modeling strategies are considered that are practical for every-day engineering calculations in an industrial environment.

PRIVATIZING AIR TRA CONTROL



Those who favor turning U.S. air traffic control over to a private corporation view the arrival of the Trump administration as their best chance in decades to get it done. Is it a good idea? Debra Werner looks at the arguments for and against shifting air traffic control out of FAA.

BY DEBRA WERNER | werner.debra@gmail.com

An air traffic controller sits at his work station at Calgary International Airport in Canada.

Nav Canada

When an airliner takes off from a U.S. airport, the air traffic controller who was responsible for the takeoff hands a strip of paper to another controller who will guide the flight listed on the paper through the next phase. This is how things work in any of the 123 airport control towers across the United States, as controllers and pilots steer planes from the gate to the runway and through the busy airspace surrounding the airport.

For critics of U.S. air traffic technology, this means of transferring responsibility for the safe and efficient routing of passenger planes is emblematic of a broader problem.

"Paper flight strips are the poster child for backwardness," says Robert Poole, who directs transportation policy for the Reason Foundation, a libertarian think tank based in Los Angeles. "Nav Canada has had electronic flight strips for nearly two decades."

Nav Canada, the nonprofit company that owns and runs Canada's civil air navigation system, is the model for those in the U.S. airline industry and Congress who want to shift responsibility for air traffic control out of the FAA. Since it began operating Canada's air traffic system in 1996, Nav Canada has adopted electronic flight strips and other technologies that have made its air navigation more efficient while improving safety. "I'm dumbfounded the United States has continued to stick with air navigation being completely within the government," says Rick Erickson, a Canadian aviation consultant.

Enter the administration of President Donald Trump, which advocates shifting air traffic control to a private corporation, an idea that has percolated for decades, most recently in a bill last year that did not make it to the full House of Representatives. A win for the Trump team will require squeezing legislation into a crowded agenda and overcoming red flags raised by skeptics. Mayors of small towns fear that a corporation might not care enough about municipal airports; U.S. senators worry about possible effects on safety and a loss of their oversight authority.

Then there is the multibillion-dollar Next Generation Air Transportation that the FAA is in the midst of rolling out. Experts agree that the effects would be significant, but predictions differ on whether the effects would be good or bad.

NextGen's competing narratives

In the U.S., 14,000 air traffic controllers handle an average of 70,000 flights a day in a 30 million-square-mile area that includes large portions of the Atlantic and Pacific Oceans and accounts for 17 percent of the world's airspace. The FAA Air Traffic Organization, which employs those controllers, has not been responsible for a fatal accident since 2013, according to records from the National Transportation Safety Board.

Maintaining that safety, though, will be increasingly challenging. The FAA forecasts that its air traffic control workload will climb 80 percent in the next two decades. To keep up with rising demand, the FAA is hiring flight controllers and adopting technology through NextGen to make it easier for controllers to safely and efficiently manage the growing number of flights.

How well is NextGen progressing? That depends on whom you ask. People who are eager to spin off air traffic control call it a disaster, and they cite years of Transportation Department Inspector General reports that point to rising costs and multiyear delays with its many projects. At the heart of NextGen will be a shift to GPS-based navigation that will require airlines to install Automatic Dependent Surveillance-Broadcast transponders onto their planes. These transponders will broadcast identity and location messages that will be received by other aircraft and also a network of towers that will feed the data into the air traffic network. The FAA planned to have ADS-B in place in 2014, but later shifted the date to 2020. Other elements have been delayed too, including System Wide Information Management, the digital backbone designed to help NextGen components share data, and En Route Automation Modernization, the computer network for FAA facilities that handle high-altitude air traffic.

Some experts fear that an attempt to overhaul air traffic control management could backfire. "Separating [air traffic control from the FAA] now would be disruptive and slow progress down," says Craig Fuller, a former head of the Aircraft Owners and Pilots Association advocacy group in Maryland and now a member of the FAA's Management Advisory Council.

Fuller and others say that under FAA Administrator Michael Huerta the NextGen initiative has turned a corner and is beginning to pay off.

Each year, the FAA publishes a NextGen cost-benefit analysis. The cost side of the equation stands at $7.5 billion, according to an FAA statement released in February. To calculate the benefits, the FAA feeds data about fuel savings, airline operating costs, FAA spending, flight delays and other factors into an economic model that estimates the value of NextGen to passengers, airlines and the U.S. government. The 2017 statement reports a cumulative $2.7 billion in benefits over the last seven years through additional flights, fewer delays, reduced FAA costs, decreased fuel consumption and less carbon dioxide emissions.

Nav Canada

▲ **A controller** in Nav Canada's Montreal-Trudeau control tower uses an electronic strip to represent each flight. Nav Canada began using the strips, which include flight data, airport and gate assignments, in 1998.

Not all are convinced. The same day the statement was released, Trump met with airline executives and declared that the FAA's modernization efforts were "totally out of whack."

For the FAA to bring NextGen to full fruition, it will have to navigate through extensive personnel and purchasing rules. Advocates of the shift say a corporation could avoid much of that. Then there are the funding issues. A corporation would not be beholden to Congress for annual appropriations and instead would raise money to update technology and facilities by issuing bonds and charging fees to air carriers.

Since 2013, the FAA's budget has remained relatively flat due, in part, to the automatic spending limits known as sequestration. To keep up with growing air traffic, modernize its infrastructure and pay for NextGen, the FAA needed its budget to increase. Congress also relies increasingly on a series of short-term spending bills to fund the FAA and other agencies instead of passing budgets annually. When Congress fails to act, money stops flowing completely as it did when the government shut down for two weeks in 2013.

The National Air Traffic Controllers Association, the union for U.S. air traffic controllers, doesn't like this financial situation. "Unfortunately, we no longer have a stable or predictable funding stream and this uncertainty has caused many serious problems for the [air traffic] system. Without change, we face continued funding uncertainty," NATCA President Paul Rinaldi told the House Transportation and Infrastructure Committee in 2016.

NATCA spokesman Doug Church notes by email that nothing has changed since last year: "The lack

COMPARISON OF AIR TRAFFIC CONTROL AGENCIES

A combination of U.S. government funds and aviation-related taxes pay for U.S. air traffic control but advocates for changes say user fees would provide a more reliable source of funding for modernization.

COUNTRY	GOVERNANCE	YEAR REFORMED	FULLY SELF-FUNDED?	FUNDING	ECONOMIC REGULATION	SAFETY REGULATION
Australia	Government corporation*	1995	Yes	User fees	Commission oversight	Separate agency
Canada	Nonprofit user cooperative	1996	Yes	User fees	Self-regulating	Separate agency
France	Government agency	2005	Yes	User fees	Approved by minister	Same agency
Germany	Government corporation	1993	Yes	User fees	Approved by minister	Separate agency
New Zealand	Government corporation	1987	Yes	User fees	Self-regulating	Separate agency
UK	Public-private partnership	2001	Yes	User fees	Price-caps	Separate agency
US	Government agency	2004	No	Ticket and fuel tax and general funds	Legislature	Same agency

Source: Eno Center for Transportation

* Nav Canada is a nonprofit corporation whose structure resembles a cooperative.

"Canada does not have the size, complexity or **diversity of operations the United States has."**

— Ed Bolen, National Business Aviation Association, on doubts about the U.S. following Canada's example

of a stable, predictable funding stream is still causing serious problems."

That desire for a reliable funding stream prompted NATCA to support legislation introduced in 2016 by Rep. Bill Shuster, the Pennsylvania Republican who chairs the House Transportation and Infrastructure Committee. Shuster's bill, which he plans to reintroduce this year, would create an independent, nonprofit corporation led by a board of directors to oversee air traffic control. Opponents of the plan call it air traffic control "privatization," while most supporters prefer the term "corporatization."

Shuster's bill, the Aviation Innovation, Reform, and Reauthorization Act, or AIRR, was the latest in a long line of proposals to move air traffic control out of government. Jim Burnley discussed the idea when he was Ronald Reagan's transportation secretary in the 1980s. Vice President Al Gore lobbied for it as part of his campaign to "Reinvent Government" in the 1990s. Last year, AIRR won the support of the House transportation committee but the bill was not voted on by the entire House.

While none of those efforts succeeded, it could be different this time around.

"There are still mountains to be climbed here politically, but we are in the best position we have been in for 30-plus years," says Burnley, now a partner in the Washington, D.C., office of the law firm Venable LLP and chairman of the Eno Center for Transportation, a think tank.

Everyone else is doing it

The Trump administration's 2018 budget blueprint released in March, known as the "skinny budget" because it was just 53 pages and not a full budget request, calls for transferring air traffic control from the FAA to an independent, nongovernmental organization, which supporters say means a private corporation. The administration has not offered further details, so no one knows how well Trump's plan lines up with Shuster's.

Shifting air traffic control out of the FAA would require the introduction of new legislation that would go through the usual legislative process before reaching Trump.


Kansas City Aviation Department

"There are still mountains to be climbed here politically, **but we are in the best position we have been in for 30-plus years."**

— **Jim Burnley**, a transportation lawyer, on prospects for shifting U.S. air traffic control to a private corporation

▲ **In the** United States, 14,000 air traffic controllers, including those at Kansas City International Airport, handle an average of 70,000 flights a day.

The administration followed up the skinny budget by having investment banker Gary Cohn, director of the White House National Economic Council, praise the idea in a meeting with U.S. business executives. "Air traffic control [reform] to me is probably the single most exciting thing we can do for a lot of reasons," Cohn said. As he sees it, an independent organization would be able to invest in technology to shorten travel times and save jet fuel. "Everyone else has done it, so we know its relatively easy to do."

While that may be an overstatement, many countries have opted to change their approach to air traffic oversight and to rely on user fees instead of taxes to cover costs. Since 1987, New Zealand, Germany, Australia, Canada and the United Kingdom have switched from government-owned, government-operated models to organizational structures ranging from government corporations to public-private partnerships. All of them also turned to user fees to cover costs. France, meanwhile, kept its air navigation agency in the government, but changed its funding source from taxes to user fees.

Countries typically charge airlines fees that vary based on the weight of the aircraft and the distance flown, an approach recommended by the United Nations' International Civil Aviation Organization. The operator of a Boeing 787 jet, for example, would pay more than the operator of a Bombardier Dash 8 turboprop to travel the same distance. Countries taking that approach issue bonds to pay for long-term capital expenditures. They point to the revenue stream to assure investors that they will be able to pay back the money.

FAA's Huerta is well aware of the push for privatization. While the FAA has carefully avoided taking sides in the debate over air traffic control's future, and none agreed to be interviewed for this article, Huerta and his supporters readily acknowledge the difficulty of updating air traffic facilities without the type of capital investment fund a private business would use and they have discussed with members of Congress whether the FAA could be given additional flexibility to borrow money.

"There is no business that would invest in major infrastructure projects without some ability to borrow," Huerta said in March at the U.S. Chamber of Commerce Aviation Summit in Washington, D.C., according to an FAA transcript. "Let's find a solution that reflects the best interests of the American people and protects the safety and flexibility of this extremely valuable public asset." FAA officials have scrupulously avoided taking sides in the debate over air traffic control's future, and none agreed to be interviewed for this article.

Opponents of privatization cite safety as their primary concern. Canadian air traffic safety has not suffered under Nav Canada, but doubters suggest that the U.S. might not have the same success.

"Canada does not have the size, complexity or diversity of operations the United States has," says Ed Bolen, who leads the National Business Aviation Association, a trade group based in Washington, D.C.

"We are modernizing air traffic control in a

Counseling patience

Even if Congress and the Trump administration agree in principle to shift U.S. air traffic control to a private corporation, it would take years to draft and pass legislation implementing the change, at least based on Canada's experience.

The Canadian government in its 1994 budget directed its Transport Canada department to look for ways to transfer some of its work outside government. Transport Canada quickly identified air navigation as a promising target, and what ensued were two years of work to define how to do it. Regulations were updated; the government determined which employees and physical assets to transfer; and it negotiated the sales price and employee benefits with Nav Canada, the nonprofit corporation established in 1995 to take over the job. In 1996, Nav Canada paid Transport Canada $1.5 billion Canadian dollars for land, buildings, aircraft, flight data processing computers, existing agreements and intellectual property.

Australia, New Zealand, the United Kingdom and Germany similarly spent years establishing their new air navigation service providers.

The challenges stem, in part, from the need to maintain air navigation services throughout the transition. "You have to keep the system running while making all of these massive changes to it," says Rick Erickson, a Canadian aviation consultant who served as a federal policy adviser when Nav Canada was created.

A few years ago, the FAA asked the Mitre Corp. to assess the experience of countries that have made this transition. The "collective experience after separating the air navigation service providers from the civil aviation authorities is quite good," Mitre concluded in the 2014 report, but "the transition process was not without difficulties in most countries." Mitre's Center for Advanced Aviation System Development created the report, "Civil Aviation Authority International Structures."

The U.S. Government Accountability Office, the investigative arm of Congress, last year cautioned lawmakers to expect complexities if they decide to make the shift. "Experts estimate that it would take a number of years to appropriately develop legislation, as well as to negotiate, plan, and implement a transition and noted that there would be associated legal, financial, and other costs for such a transition," GAO said in a report, "Air Traffic Control: Experts' and Stakeholders' Views on Key Issues to Consider in a Potential Restructuring."

— Debra Werner

much larger, much more sophisticated, much more complex air traffic system than other countries have," adds Fuller of the FAA Management Council. "Some things we are doing faster, others not as fast, but we are doing it by maintaining a tremendous safety record."

The bottom line

Shuster proposes creating a board of directors to oversee the nonprofit air traffic control organization. Board members would be selected by the U.S. Transportation secretary and organizations representing major airlines, private pilots, business aviators, air traffic controllers, airline pilots and aerospace manufacturers. Under the legislation introduced in 2015, airlines would have selected four members of the 13-person board.

Bolen, of the business aviation association, has concerns about giving airlines that kind of power. "It's hard to believe they would want to run the air traffic system in the public's best interest as opposed to their companies' best interests," he says. "The airlines operate for the bottom line. Some would argue that is their fiduciary responsibility."

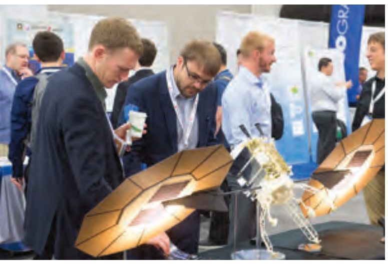
He's not alone in his skepticism. After Trump's March budget proposal, 128 small-town mayors spanning all 50 states sent a letter to Shuster and his Democratic counterpart on the House transportation committee, Rep. Peter DeFazio, D-Ore. "Privatization would hand over decisions about infrastructure funding, taxes and fees, consumer complaints, noise, and many other priorities to a board of private interests dominated by commercial airlines," they wrote. "These are the same airlines that have cut back flights to smaller communities by more than 20 percent in recent years."

A month earlier, a bipartisan group of four Senate appropriators cited additional reasons for opposition. In a letter to the panel that authorizes FAA spending, they complained that Shuster's legislation would "separate air traffic control functions of the FAA from critical safety" programs and hurt oversight efforts meant to "ensure accountability for program performance and a sustained focus on aviation safety."

For supporters of the Shuster legislation or similar proposals, the opposition of Sens. Thad Cochran, R-Miss.; Patrick Leahy, D-Vt.; Susan Collins, R-Maine; and Jack Reed, D-R.I., amounts to a high hurdle. "The appropriators are very powerful," Burnley says. "They are not going to go quietly into the night."

That would mean paper flight strips will be around for some more years but not indefinitely. The FAA plans to roll out electronic flight strips nationwide from 2020 to 2028. ★

Participation is Power



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"The ability to network with people from all over...where you're not running all over the place, has been terrific."

—**Edgar G. Waggoner**, *Director, Integrated Aviation Systems Program, NASA Aeronautics Research Mission Directorate*

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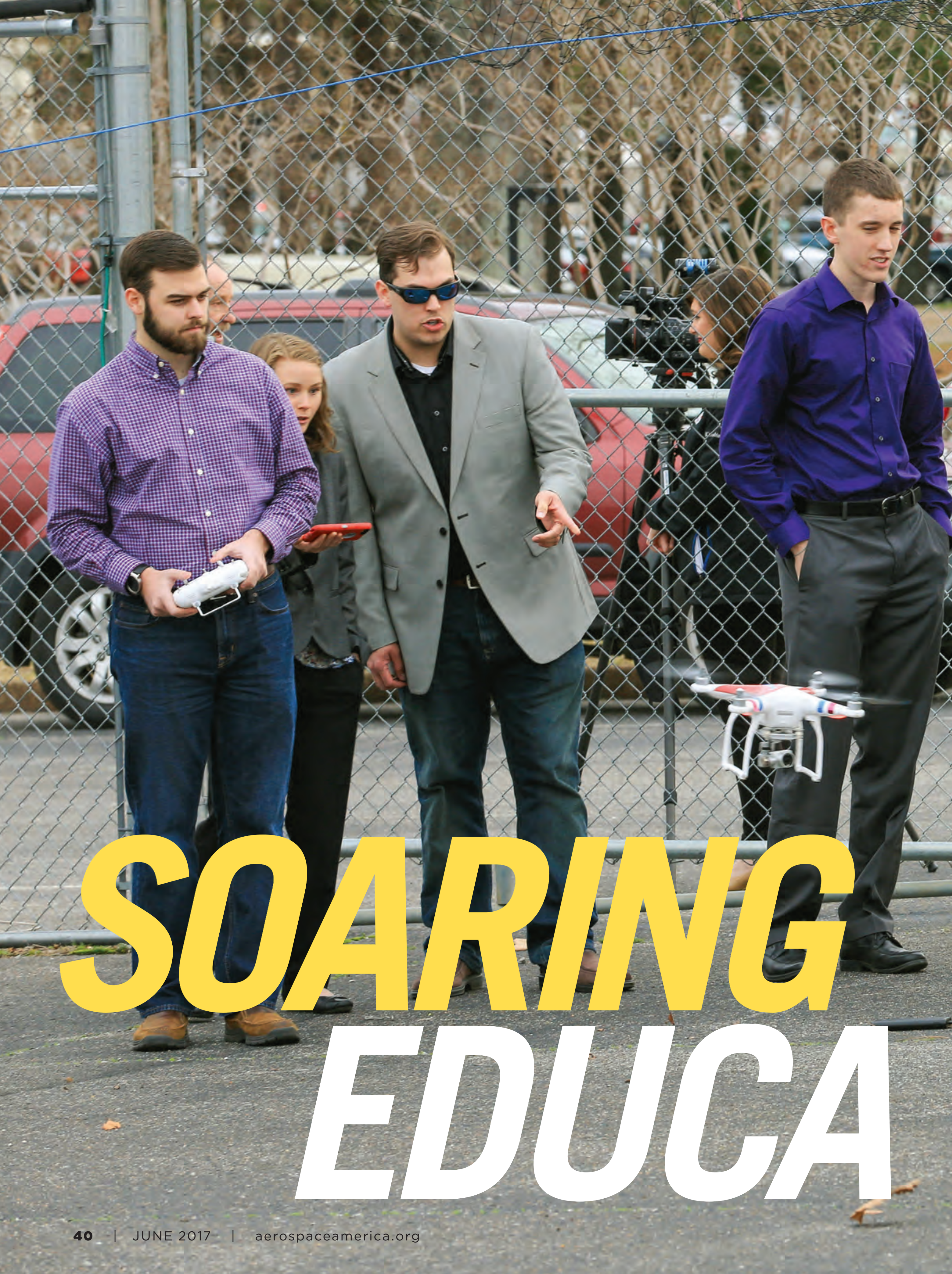
Shaping the Future of Aerospace



SOARING EDUCA

Students at the University of Alabama at Huntsville and their professor test their plan for intercepting drones without destroying them. Aerospace educators guide students on real-world projects during class time.

Photo by Michael Mercier/UAH

In the fast-moving field of aerospace engineering, educators are preparing their students for the future by incorporating some surprising teaching tools and methods. Adam Hadhazy tells the story.

TION

BY ADAM HADHAZY | adamhadhazy@gmail.com

Aerospace engineering educators have embraced change pretty much since the first college-level program was offered in the United States in 1914 under the heading "aeronautical" engineering. Course material expanded with the advent of commercial airlines, helicopters, plus two world wars worth of aerial missions. The Space Age brought the term "aerospace," thus extending educators' purview into the final frontier.

Today, aerospace educators are innovating technically and pedagogically in ways that their 20th-century predecessors would likely applaud. Teachers and students are increasingly turning to a range of tools, from ubiquitous internet and smartphones to online simulation apps and 3-D printers. Highly affordable drones and tiny satellites called cubesats are further expanding curricula and opportunities for students to design, build and fly.

"Twenty years ago, there was more of a traditional, classwork style setting, where you have someone on a stage talk and talk, and then the students go home. We're shifting from that to a more hands-on, more proactive learning approach," says Adeel Khalid, an associate professor in mechanical and systems engineering at Kennesaw State University in Georgia and president of the Aerospace Division of the nonprofit American Society for Engineering Education based in Washington, D.C.

Traditionally, most undergraduate students waited until their senior semesters to take on an intensive, capstone development project bringing together various bits of theory and experimentation from earlier courses. That is no longer the case.

"We make sure we start right away doing hands-on build and design freshman year; we don't just leave it for graduating seniors," says Dava Newman, a professor of aeronautics and astronautics at MIT and a former NASA deputy administrator. "Students learn by doing."

In short, students are commonly invited or even required to participate in the skills-building fun of physical craftsmanship.

Here is an in-depth look at some of the innovative methods and ideas educators are deploying nationwide to train the next generation of aerospace engineers.

"EVERY AIRCRAFT HAS A STORY BEHIND IT, A REASON FOR ITS EXISTENCE, A MISSION IT WAS DESIGNED FOR. AND EVERYBODY LIKES STORIES."

— Adeel Khalid, American Society for Engineering Education

Breaking the mold

Taking cues from other disciplines, aerospace engineering programs are integrating a pedagogical technique known as the flipped classroom. Rather than sitting through lectures to prepare them to complete homework, students in this new approach spend time outside the classroom watching video lectures, reading books or engaging in website tutorials. The time in class is switched over to tackling homework-style exercises, asking questions and, quite often, meeting up in an engineering lab. "The students can go to an apparatus, like a wind tunnel, a flight simulator, or an engine test bench," says Khalid, "and actually run an experiment that's relevant to the theory they read about the night before."

Making the transition to a flipped classroom is at first challenging for students accustomed to the conventional approach. "It takes students a week or two to adjust, but then a lot of them really enjoy it," says Khalid. He has found that his students and those of colleagues benefit from the inside-out arrangement. "I've noticed that their understanding, maturity and learning has increased substantially in the flipped classroom environment," Khalid says.

Some teachers are also exposing students to concepts and issues beyond the typical parameters of aerospace engineering. "What we're doing more and more is going to other majors and not just keeping within aerospace," says Brian Landrum, an associate professor of mechanical and aerospace engineering at the University of Alabama in Huntsville.

At UAH, instructors guide undergrads in the engineering instruments lab to work with students in the College of Nursing. The student nurses come up with problems in need of aero solutions. One example: devising a remote-controlled drone for disaster response. The nurses identified which supplies would be most needed, and the engineers figured out how to quickly and securely deliver them to the scene.

Other times, biology majors have advised aero students on "biomimicry" projects, in which students derive designs by studying nature, such as how a butterfly flaps its wings to climb.

Connected classrooms

Flipped or not, the lecture hall remains a mainstay of aerospace engineering education. But teachers are finding ways of making it a less static, more stimulating environment.

A good starting point is the vastness of online information that students can view in the classroom on their smartphones and on large but surprisingly affordable wall-mounted screens. Pencils, notepads and textbooks still have their place, but aerospace students can have reference material flow digitally, enhancing learning potential, instead of distracting from it. "In my classroom, everything is web-connected," says Landrum. "It's really easy to connect and get information."

This is a major cultural shift. "There was a time, not too long ago, where people were discouraged from using cellphones and tablets and laptops in the classroom because they were disruptive," says Khalid. "Now we're encouraging people to use those devices to learn actively."

Khalid often asks his students to take half a minute to look up and share with the class other examples of the aircraft type currently under discussion. To get students initially interested, Khalid explains why a particular aircraft is designed just so, from a heavy cargo, military vehicle like the Lockheed C-5 Galaxy to a fleet-footed Airbus Helicopters' H155 civilian chopper.

"Every aircraft has a story behind it, a reason for its existence, a mission it was designed for. And everybody likes stories. I can stand in front of a class and talk theory, but that gets boring quickly," Khalid says.

To fight boredom and optimize content absorption, some professors are adopting what are called classroom response systems, a popular one being Poll Everywhere. These services work as follows: Students log onto a website or app on their phones during class and indicate their grasp of the concept that's being taught. Poll results are posted on a screen at the front of the classroom. If a lot of people are just not getting it, the duly informed teacher can spend additional time explaining the tricky aerospace concept. This instant feedback beats the traditional asking for a show of hands, which MIT's Newman calls "kludgy." Not only time-consuming, the old-fashioned method suffered because some students would feel embarrassed about publicly declaring their bewilderment.

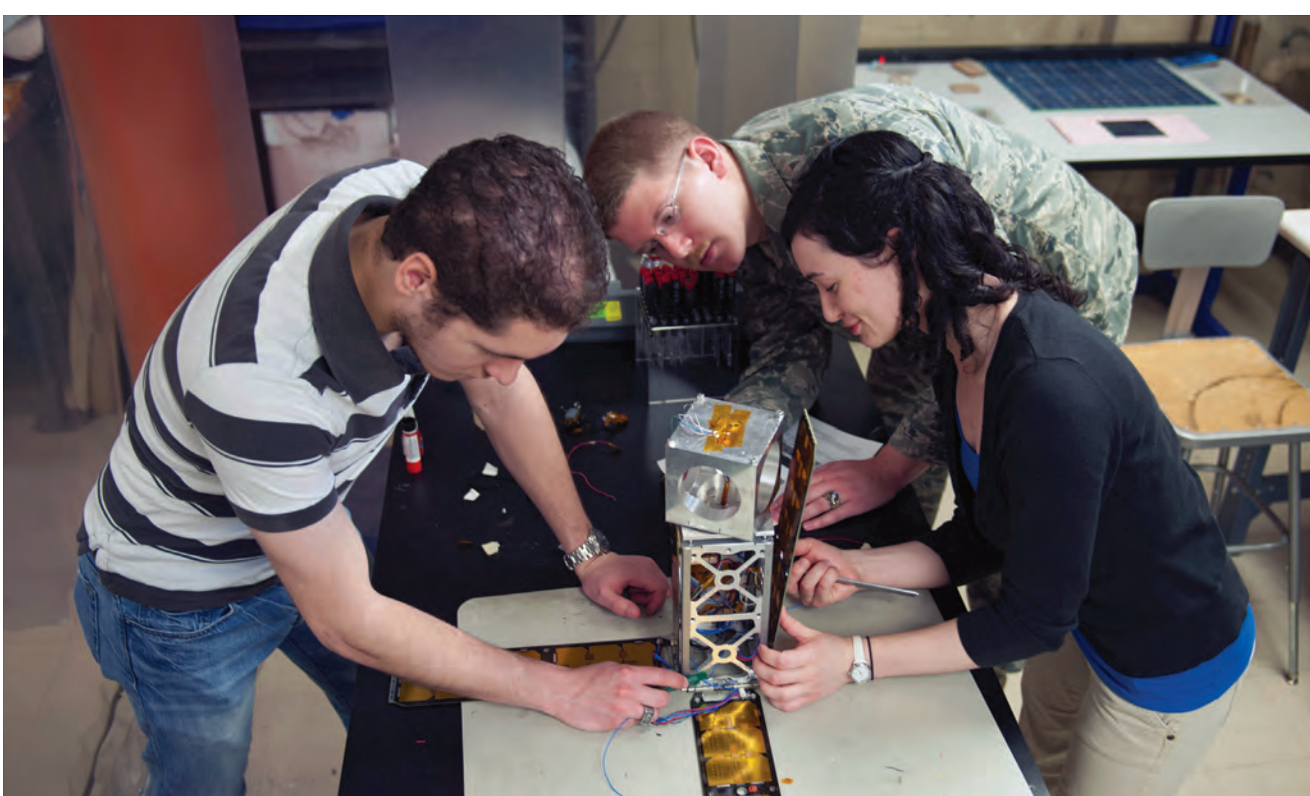
Labs on demand

Some students grasp classroom concepts quickly, but are hobbled by confusion when it comes to operating the machines in the laboratory and workshop. They might not fully grasp the insights the apparatuses can offer for a given project. An increasingly popular strategy calls for letting the lab come to them, so to speak, through a suite of online, virtual laboratories that are becoming ever more powerful and utilized.

"There's a virtual environment emerging," says Darryll Pines, dean of the Clark School of Engineering at the University of Maryland. "While they will never duplicate being in the lab, the programs help students understand the phenomena and physics you're trying to convey to them."

Some popular (and sometimes free) online software applications simulate functional wind tunnels, airfoil lift and drag calculations, jet engine functions, fluid- and aerodynamic flow, and more. The benefits are manifold. One is that access to equipment, like large-scale wind tunnels, is not available to every school. Another benefit is that students can access

▼ **MIT students** work on the Microsized Microwave Atmospheric Satellite, a joint project with MIT's Lincoln Laboratory, that was deployed from the International Space Station.



William Litant/MIT

University of Maryland

the applications "24/7, right from their dorm rooms," says Newman. That includes late at night, when more than a few students prefer to do their studying.

Experience breeds familiarity, and expertise. "Students can go in and tweak all these parameters," Newman says. "They're going to enjoy it, first of all, and spend more time with it, and that's how they can really learn more." As a result, when students do enter the physical lab, they will have a much better designed experiment and knowledge of the apparatuses' capabilities.

▲ **Josh Gaus**, a student at University of Maryland Clark School of Engineering, was an intern at the university's UAS Test Site in 2016. Summer interns work on a project with a faculty adviser and are paid an hourly rate, in addition to learning under the guidance of the site's operations team.

Refining refinement

For many teachers, the 3-D printer has emerged as the newest must-have tool for teaching rapid prototyping. Decent 3-D printers can be had for a few hundred dollars nowadays, so academic labs have accordingly stocked up. Students can crank out model after model for testing and design refinement.

"YOU'VE GOT TO HAVE A KIND OF BALANCE. IF YOU GET TOO ADVANCED, YOU LOSE SIGHT OF THE MORE FUNDAMENTAL STUFF."

— **Brian Landrum**, an associate professor of mechanical and aerospace engineering at the University of Alabama in Huntsville

Students can now draw a design and within hours translate them into a physical model. Modifying a parameter, like an airfoil shape, can be done with a few keyboard clicks. Put another way, students can fail faster and more often, which Newman says is an excellent approach to learning the ropes of aerospace engineering: "A lot of design is iteration."

In a similar vein, schools are acquiring their own quadcopters and other drones for student experimentation. These aircraft are now inexpensive enough to cross over as mass-market holiday gifts. Newman says students can tinker with aerodynamics, remote-control interfaces, signaling, data transmission from cameras and sensors, and other computer-coding, related systems.

"All engineers are hackers on one level or another," she says, "and these aircraft let them test out their own algorithms and controls."

Kennesaw's Khalid also points out that drones are pushing the aerospace education field forward in a subtler manner, by forcing students to consider the "human factor," the operator's remote views and other information streams, communications for maintaining control, and expediting repairs back at base.

Then there are the tiny cubesats that can weigh barely more than a kilogram, although sometimes more when multiple units are joined. Cubesats are built to an industry standard so that they can be released into orbit from any launch vehicle or spacecraft equipped with the proper dispenser. They have been dispatched by the hundreds into orbit in recent years, including from the International Space Station and from U.S. government and privately owned launch vehicles. Teachers and their students can equip them with rudimentary cameras and other sensors to send data back to Earth. Getting one on-orbit costs only a few tens of thousands of dollars, well within many university budgets. Scores of schools have built or are building their own cubesats, granting their engineering students some genuine spaceflight hardware experience. "It's a cubesat revolution," says Newman.

Looking ahead, looking back

The teaching innovations seen in the first part of the 21st century probably amount to scratching the surface. Professors are beginning to think about how artificial intelligence and quantum computing might be applied someday.

Nearer-term, interest is growing in augmented reality as a technology that could make classrooms still more dynamic. This technology overlays computer-generated visuals on top of students' views of the classroom on a phone's display screen, à la the Pokémon Go app. If the price of augmented reality headsets comes down, students will likely look through those. Students could feast their eyes and minds on, say, interactive schematics of engines or air rushing past nosecones.

Newman says MIT is certainly interested. "I think we're right on the cusp of being in a really immersive educational environment," she says. Newman can imagine a high-definition panorama of Mars, where students would feel like "space-suited Martian astronauts." This would be a compelling way to virtually explore space or develop landing-craft development for interplanetary missions.

For all the high-tech components in modern aerospace education, something important to hang onto, UAH's Landrum argues, is familiarity and fluency in physical and mechanical principles. He requires his sophomore students to fashion tiny planes out of objects taken from the trash, powered by a rubber band-wound motor, that must carry pennies a minimum distance. The project can be a challenge to today's students, Landrum says. Many of their self-taught skills are in programming and robotics, and less so in the building of model planes and rockets so popular in generations past. Both are valuable for a well-rounded education.

"You've got to have a kind of balance. If you get too advanced, you lose sight of the more fundamental stuff," Landrum says, joking, "I have an old-school side, too." ★

Selling Mars as Planet B

Of all the reasons to go to Mars, the need to ensure that our species can survive is beginning to ring the loudest. Tom Risen received some surprising insights when he spoke to environmentalists, Mars-exploration advocates and science fiction writers about this idea.

BY TOM RISEN | tomr@aiaa.org

Science fiction has dramatized the idea; physicist Stephen Hawking argues its urgency and Elon Musk founded SpaceX to pursue it. It's the notion that humans must build a colony on Mars as a backup planet to ensure humanity's survival if Earth becomes uninhabitable.

Hawking has for years touted interstellar travel as the preferred way to one day propel humanity to outlive what he sees as the increasing risk of extinction from natural and human-made disasters on Earth. The pioneering physics professor at the University of Cambridge has also mentioned Mars or the moon as near-term safe havens.

"Hawking thinks the human species will have to populate a new planet within 100 years if it is to survive," says the BBC in a press release about his upcoming TV documentary, "Expedition New Earth." The BBC explains: "With climate change, overdue asteroid strikes, epidemics and population growth, our own planet is increasingly precarious."

Musk has long favored Mars colonization as a means to survive what he calls an "inevitable" extinction event on Earth. On its website, SpaceX says that the company was founded in 2002 "with the ultimate goal of enabling people to live on other planets." The tech entrepreneur reiterated that survivalist message in September at the International Astronautical Congress in Mexico, saying humans have to become "a multiplanetary species" and build complete cities on Mars with all the amenities, including "iron foundries, pizza joints, you name it."

Voices in popular culture and social media have echoed this argument for why NASA and its presumed international partners should spend years of work and billions of dollars sending humans to Mars. Interviews with a broad range of scientists and futurists, however, reveal skepticism about the wisdom and feasibility of selling Mars as "Planet B."

The implication that Mars colonization should be prioritized over fixing Earth's problems, such as climate change, unsettles Katharine Hayhoe, director of the Climate Science Center at Texas Tech University.

"Mars is not an escape hatch for planet Earth," Hayhoe says. "If we do not take action to reduce and eventually eliminate our carbon emissions, they will overwhelm human civilization as we know it, long before Mars is ready to be colonized by large numbers of people."

A Mars colony would need a huge investment of supply ships to keep settlers alive in the toxic, freezing Martian environment, but the numerous abandoned bases in Antarctica show that building cities in less hazardous places on Earth is difficult enough. Advocates of a colony tout the potential to mine water and rare minerals on the red planet, but searching for resources or avoiding a potential asteroid strike on Earth are not immediate enough motivations to inspire a Mars settlement, says Andy Weir, author of "The Martian," which depicts an astronaut stranded on Mars.

"I don't believe there will ever be a permanent settlement on Mars or the moon or anywhere else off Earth until there's an economic reason for it," Weir says. "Whatever Earth's problems are, it's considerably easier to fix Earth than it is to colonize Mars."

"Whatever Earth's problems are, it's considerably easier to fix Earth than it is to colonize Mars."

— Andy Weir, author of "The Martian"

The Curiosity rover shot this photo of Mount Sharp on Mars in 2012.

NASA

The Mars Society

▲ **The Mars Society** trains future explorers at research stations like this one in the Canadian Arctic.

Weir and others consider Mars an inhospitable place where the first goal should be research rather than settlement, at least for the near future. Pascal Lee, a planetary scientist at NASA's Ames Research Center in California, points to exploration of Antarctica as a realistic model for how Mars might be studied. International research stations on Antarctica host rotating scientific teams, and this strategy has kept a sustained but limited human presence there.

"There is an escapism to wanting to go to Mars and start anew," Lee says of the appeal of colonization. "The issue with that particular enticing concept is — 'to go to what?' You would need an entire infrastructure set up in advance to support people there."

Missions to Mars don't need to result in colonization to improve humanity's chances of survival, says Robert Zubrin, president of the nonprofit Mars Society, which advocates for research to explore and study the red planet. The Mars Society is training people at research stations in the Canadian Arctic and the Utah desert to simulate life on Mars. "A culture which is going to Mars is going to be much more adept at furthering its prospects on Earth," Zubrin says.

Zubrin is bullish on exploration, but says he "doesn't see merit" in the concept of colonizing Mars to ensure that at least some humans would live on after a catastrophe on Earth like a massive asteroid strike.

That said, Zubrin expects "Mars will be a pressure cooker for innovation because you have to adapt." By exploring Mars, scientists and engineers could uncover new technologies to deflect asteroids and also improve medicine or grow more productive crops on Earth.

"By becoming a spacefaring species we will gain greater control over our environment, which is essential to our long-term survival," he says.

If colonization were to be attempted, how might that work? A future where millions of humans live on Mars is central to the story of "The Expanse," a TV show on the Syfy Channel inspired by novels written by Daniel Abraham and Ty Franck.

Abraham says logistics would be a challenge to making this fantasy a reality. "Moving large populations from one planet to another with present or foreseeable technology is like drinking a lake through a coffee straw," he says. "The more likely scenario to me is that we make Mars, Venus, Europa or wherever we're aiming for a habitable, sustainable environment and then build up the population in the traditional way."

Humanity's need to explore and expand has not always been a positive instinct, Franck says. On the show, the vision of colonization is far from utopian, as an independent Mars government and a crowded Earth are on the brink of war.

He and Abraham caution against looking at Mars as an escape from the side of human nature that Hawking fears could threaten life on Earth.

"Humanity isn't likely to change much, whatever context you put us in," Abraham says. "If the barrier to space exploration is that we have to change human nature first, we're kind of sabotaging the project at the start, right?" ★

AIAA Bulletin

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

Calendar

Notes About the Calendar

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

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2017			
3–4 Jun †	Dawn of Private Space Science Symposium 2017	New York, NY (Contact: www.privatespacescience2017.com)	
3–4 Jun	1st AIAA Geometry and Mesh Generation Workshop	Denver, CO	
3–4 Jun	3rd AIAA CFD High Lift Prediction Workshop	Denver, CO	
3–4 Jun	Optimal Design in Multidisciplinary Systems Course	Denver, CO	
3–4 Jun	Practical Methods for Aircraft and Rotorcraft Flight Control Design and Hands-On Training Using CONDUIT® Course	Denver, CO	
5–9 Jun	AIAA AVIATION Forum (AIAA Aviation and Aeronautics Forum and Exposition) Featuring: – 24th AIAA Aerodynamic Decelerator Systems Technology Conference – 33rd AIAA Aerodynamic Measurement Technology and Ground Testing Conference – 35th AIAA Applied Aerodynamics Conference – AIAA Atmospheric Flight Mechanics Conference – 9th AIAA Atmospheric and Space Environments Conference – 17th AIAA Aviation Technology, Integration, and Operations Conference – AIAA Flight Testing Conference – 47th AIAA Fluid Dynamics Conference – 18th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference – AIAA Modeling and Simulation Technologies Conference – 48th Plasmadynamics and Lasers Conference – AIAA Balloon Systems Conference – 23rd AIAA Lighter-Than-Air Systems Technology Conference – 23rd AIAA/CEAS Aeroacoustics Conference – 8th AIAA Theoretical Fluid Mechanics Conference – AIAA Complex Aerospace Systems Exchange – 23rd AIAA Computational Fluid Dynamics Conference – 47th Thermophysics Conference	Denver, CO	27 Oct 16
5 Jun	Cybersecurity Symposium at AIAA AVIATION Forum	Denver, CO	
6–7 Jun	DEMAND for UNMANNED at AIAA AVIATION Forum	Denver, CO	
6–9 Jun†	8th International Conference on Recent Advances in Space Technologies (RAST 2017)	Istanbul, Turkey (Contact: www.rast.org.tr)	
7–9 Jun	Transformational Electric Flight Workshop & Expo at AIAA AVIATION Forum	Denver, CO	
19–21 Jun†	9th International Workshop on Satellite Constellations and Formation Flying	Boulder, CO (Contact: http://ccar.colorado.edu/iwscff2017)	
27–28 Jun†	Cognitive Communications for Aerospace Applications (CCAA) Workshop	Cleveland, OH (Contact: www.ieee.org/CCAA)	
8–9 Jul	Emerging Concepts in High Speed Air-Breathing Propulsion Course	Atlanta, GA	
8–9 Jul	Hybrid Rocket Propulsion	Atlanta, GA	
8–9 Jul	Liquid Rocket Engines: Fundamentals, Green Propellants, & Emerging Technologies Course	Atlanta, GA	
8–9 Jul	Missile Propulsion Design, Development, and System Engineering Course	Atlanta, GA	
8–9 Jul	Turbulence Modeling for Modern Industrial CFD Course	Atlanta, GA	
10–12 Jul	AIAA Propulsion and Energy Forum (AIAA Propulsion and Energy Forum and Exposition) Featuring: – 53rd AIAA/SAE/ASEE Joint Propulsion Conference – 15th International Energy Conversion Engineering Conference	Atlanta, GA	4 Jan 17
20–24 Aug†	2017 AAS/AIAA Astrodynamics Specialist Conference	Stevenson, WA	24 Apr 17
22–24 Aug†	International Conference on Aerospace Science and Engineering (ICASE)	Islamabad, Pakistan (Contact: http://www.ist.edu.pk/icase)	
10–11 Sep	Decision Analysis Course	Orlando, FL	
11 Sep	Space Standards and Architectures Workshop	Orlando, FL	
12–14 Sep	AIAA SPACE Forum (AIAA Space and Astronautics Forum and Exposition)	Orlando, FL	23 Feb 17
13–16 Sep†	21st Workshop of the Aeroacoustics Specialists Committee of the Council of European Aerospace Societies (CEAS)	Dublin, Ireland	

†Meetings cosponsored by AIAA. Cosponsorship forms can be found at https://www.aiaa.org/Co-SponsorshipOpportunities/.

AIAA Continuing Education offerings

AIAA Symposiums and Workshops

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
25–29 Sept†	68th International Astronautical Congress	Adelaide, Australia	28 Feb 17
16–19 Oct†	Joint 23rd Ka and Broadband Communications Conference and 35th International Communications Satellite Systems Conference (ICSSC)	Trieste, Italy (www.kaconf.org)	10 May 17
13–15 Nov†	1st International Academy of Astronautics (IAA) Conference on Space Situational Awareness	Orlando, FL (www.icssa2017.com)	
2018			
6–7 Jan	5th International Workshop on High-Order CFD Methods Workshops	Orlando, FL	
6–7 Jan	Challenges and Opportunities in Aerospace CFD: Achieving the CFD2030 Vision Workshops	Orlando, FL	
8–12 Jan	AIAA SciTech Forum (AIAA Science and Technology Forum and Exposition) Featuring: – 26th AIAA/AHS Adaptive Structures Conference – 56th AIAA Aerospace Sciences Meeting – AIAA Atmospheric Flight Mechanics Conference – AIAA Information Systems — Infotech@Aerospace Conference – AIAA Guidance, Navigation, and Control Conference – AIAA Modeling and Simulation Technologies Conference – 20th AIAA Non-Deterministic Approaches Conference – 28th AAS/AIAA Space Flight Mechanics Meeting – 59th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference – 5th AIAA Spacecraft Structures Conference – 36th Wind Energy Symposium	Orlando, FL	12 Jun 17
22–25 Jan †	64th Annual Reliability & Maintainability Symposium (RAMS)	Reno, NV (Contact: http://www.rams.org)	
3–10 Mar †	IEEE Aerospace Conference	Big Sky, MT (Contact: www.aeroconf.org)	
8–10 May	AIAA DEFENSE Forum (AIAA Defense and Security Forum), Featuring: – AIAA Missile Sciences Conference – AIAA National Forum on Weapon System Effectivenss – AIAA Strategic and Tactical Missile Systems Conference	Laurel, MD	
28–30 May †	25th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (Contact: www.elektropribor.spb.ru)	
28 May–1 Jun	SpaceOps 2018: 15th International Conference on Space Operations	Marseille, France (Contact: www.spaceops2018.org)	6 Jul 17
25–29 Jun	AIAA AVIATION Forum (AIAA Aviation and Aeronautics Forum and Exposition) Featuring: – 24th AIAA/CEAS Aeroacoustics Conference – 34th AIAA Aerodynamic Measurement Technology and Ground Testing Conference – 36th AIAA Applied Aerodynamics Conference – AIAA Atmospheric Flight Mechanics Conference – 10th AIAA Atmospheric and Space Environments Conference – 18th AIAA Aviation Technology, Integration, and Operations Conference – AIAA Flight Testing Conference – 9th AIAA Flow Control Conference – 48th AIAA Fluid Dynamics Conference – 12th AIAA/ASME Joint Thermophysics and Heat Transfer Conference – AIAA Modeling and Simulation Technologies Conference – 19th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference – 49th Plasmadynamics and Lasers Conference	Atlanta, GA	
3–6 Jul †	ICNPAA-2018 - Mathematical Problems in Engineering, Aerospace and Sciences	Yerevan, Armenia (Contact: http://www.icnpaa.com)	
9–11 Jul	AIAA Propulsion and Energy Forum (AIAA Propulsion and Energy Forum and Exposition) Featuring: – 54th AIAA/SAE/ASEE Joint Propulsion Conference – 16th International Energy Conversion Engineering Conference	Cincinnati, OH	
27–29 Aug	AIAA SPACE Forum (AIAA Space and Astronautics Forum and Exposition) Featuring: – AIAA Complex Aerospace Systems Exchange	New Orleans, LA	

2017 AIAA Aerospace Spotlight Awards Gala

AIAA presented its highest awards at the AIAA Aerospace Spotlight Awards Gala on 3 May, at the Ronald Reagan Building and International Trade Center, in Washington, DC. Inside the building's soaring atrium, nearly 400 people gathered to celebrate our community's luminaries. And what a great evening it was – from the presentation of the newly elected Class of 2017 Fellows and Honorary Fellows, to the presentation of all of the evening's awards, the atrium ballroom resounded with enthusiastic applause as our community's best and brightest were recognized.

For more information about the AIAA Honors and Awards Program, contact Patricia Carr at patriciac@aiaa.org or 703.264.7523.

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1 Class of 2017 Fellows and Honorary Fellows.

2 AIAA President James Maser (right) with Bob Winn of Engineering Systems Inc., 2017 recipient of the AIAA Distinguished Service Award.

3 Maj. Gen. Charles F. Bolden Jr. (left), 2017 recipient of the AIAA Public Service Award, with AIAA President James Maser.

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4 (Left to right) AIAA President James Maser presented the 2017 AIAA International Cooperation Award to John C. Vassberg, The Boeing Company; Melissa B. Rivers, NASA Langley Research Center; and Richard A. Wahls, NASA Langley Research Center.

5 AIAA President James Maser (right) with 2017 AIAA Reed Aeronautics Award recipient, Edward M. Greitzer, of the Massachusetts Institute of Technology.

6 (Left to right) AIAA President James Maser with the 2017 AIAA Foundation Educator Achievement Award recipients— Kevin Simmons, David Root, Alexandra Kindrat, Tracey Dodrill, and Kathy Biernat—and AIAA Executive Director Sandy Magnus.

7 William H. Gerstenmaier, NASA (left), 2017 recipient of the AIAA Goddard Astronautics Award, with AIAA President James Maser.

8 NASA Langley Research Center is the 2017 recipient of the AIAA Foundation Award for Excellence. David E. Bowles (left), NASA Langley director, accepted the award from AIAA President James Maser.

University Of Southern California Wins 21st Annual Student Design/ Build/Fly Competition

The 2016–2017 Textron Aviation/Raytheon Missile Systems/AIAA Foundation Student Design/Build/Fly (DBF) Competition was held 20–23 April, at the Tucson International Modelplex Park Association (TIMPA) Airfield, Tucson, AZ. The event included 73 teams and 754 students.

The DBF competition promotes excellence in aerospace engineering skills at the undergraduate and graduate levels by challenging teams to design and fabricate a radio-controlled aircraft conforming to strict guidelines, submit a written report about the aircraft's design, fly their aircraft over a defined course while carrying a payload, and land it without damage. This year, the design simulated a manually launched unmanned aerial system.

The University of Southern California, Los Angeles, won the event by a small margin and the team from the Georgia Institute of Technology came in second place. The competition's highest placing international team and the third-place winner was the University of Ljubljana, Ljubljana, Slovenia.

Official results and rankings for all participants will be available from the DBF website after their final verification and validation. For more information about the Textron Aviation/Raytheon Missile Systems/AIAA Foundation DBF Competition, please visit http://www.aiaadbf.org.


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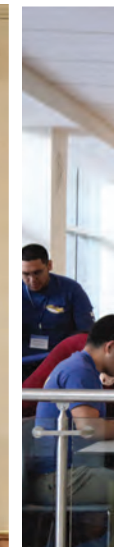
News

2017 AIAA Regional Student Conferences



The AIAA Regional Student Conferences, technical paper competitions held in each AIAA Region, give undergraduate and graduate students an opportunity to present their research on aerospace topics in a formal technical meeting atmosphere. Students are judged for technical content and clarity of communication by professional members from industry. The conference also provides a venue for students to share AIAA experiences, participate in social activities, connect with professionals, and exchange ideas about current topics in aerospace engineering. Support for the student conferences is provided by the AIAA Foundation and the Region's professional members.

The AIAA Foundation awards prizes to the top three winners in the Masters, Undergraduate, and Team categories. The first-place winners of the Regional Student Conferences are invited to participate in the AIAA Foundation's International Student Conference, held each January in conjunction with the AIAA SciTech Forum. This event gives students an opportunity to meet winners from other AIAA Regions, network with professionals from industry, and present their work to a new set of judges. The students' papers are also published as part of the AIAA SciTech.

(*Region VII—Australia Student Conference will take place 23–24 November at Royal Melbourne Institute of Technology (RMIT) in Melbourne.*)

TECHNICAL PAPER – MASTERS

Region I: Sensitivity Analysis of the First Order Reliability Method for Reliability Based Design Optimization, Patrick R. Clark, Virginia Polytechnic Institute and State University

Region II: Linear Inlet Optimization for Capture of River Kinetic Energy, Chiu P. Yan, University of Memphis

Region III: PIV Analysis of Flow around Real Elephant Seal Whiskers, Joseph Bunjevac and Wei Zhang, Cleveland State University

Region IV: Understanding Unsteady Aerodynamics of Cyloidal Rotors in Hover at Ultra-low Reynolds Numbers, Carolyn Walther, Texas A&M University

Region V: NA

Region VI: Origami-based Tunable Structures with Simultaneously Foldable and Stiff Behavior, Balakumaran Gopalarethinam, University of Washington

Region VII (Europe/Pegasus): Non-linear Estimation Methods for Aircraft Dynamic Parameters During Taxiing, Thibault Marduel, Institut Supérieur de l'Aéronautique et de l'Espace, & Francois Pineau and Laurent Georig, Dassault Aviation

TECHNICAL PAPER – UNDERGRADUATE

Region I: GPU Acceleration of Helicopter Flow Field Simulation, Eric Wallace, University of Maryland

Region II: IEC Plasma Thruster, Johnie Sublett, Mississippi State University

Region III: Simulations and Preliminary Measurements of a Magnetic Nozzle Thrust Vectoring System, Beldon Lin and J.P. Sheehan, University of Michigan

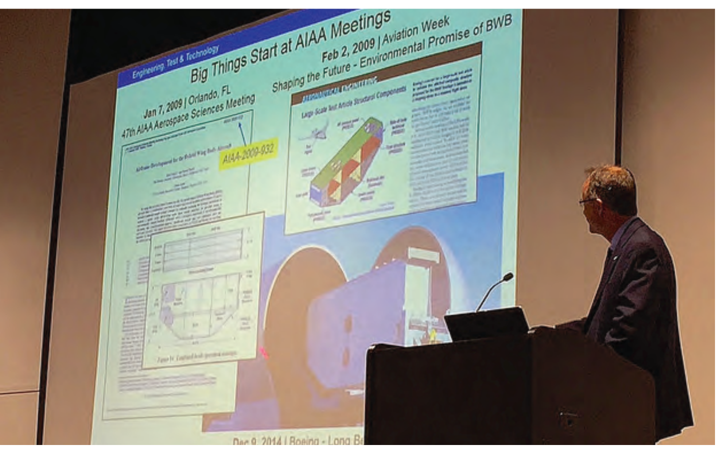
Region IV: Small-Scale Turbojet Thrust Augmentation from a Jet Pipe with a Bellmouth Inlet, Matt Durkee, Oklahoma State University

Region V:
- Comparison of Low Pressure Turbine Trailing Edge Blowing Techniques for Wake Loss Reduction, Young Y. Wu, United States Air Force Academy
- Development of a Flush Air Data System for the Space X Dragon Crew Capsule, Nicholas Carpenter, John Deaton, United States Air Force Academy

Region VI: Design and Characterization of a Cylindrical-Orifice Injector for High-Viscosity Monopropellants, Greg Derk and Angela Kimber, University of Washington

TECHNICAL PAPER – TEAM

Region I: Virginia Tech-NASA Auto-deployable Mars Rover Design and Development Project, Ian Stewart, Tommy Cleckner, Eddie Krutyanskiy,



Aaron Knust, Aldo Morales, Christopher Nickles, Greta Ostergaard, Jacob Walder, and Robert Zakotnik, Virginia Polytechnic Institute and State University

Region II: Concept Study of a Reusable Suborbital Launch Vehicle, Jared Fuchs, Matthew Haskell, Benjamin Thompson, Tate Harriman, and William Hankins, University of Alabama in Huntsville

Region III: Complete Design and Build of a Convectively Cooled Rocket Nozzle Test Bed, Austin Harms, Abhiram Krishnan, and Nathan Williams, University of Michigan

Region IV: A New Approach on Sampling Microorganisms from the Lower Stratosphere, Jamie N. Lehnen, Bryan L. Gunawan, and John R. Prince, University of Houston

Region V: Project REPTAR Recoverable ProTection After Re-entry, Calvin Buechler, Kevin Faggiano, Dustin Fishelman, Cody Gondek, Lee Huynh, Aaron McCusker, William Sear, Himanshi Singhal, Craig Wenkheimer, and Nathan Yeo

Region VI: Design of a Paddle-Driven Wave Generator, Henry Miskaryan, David Freeman, Andrew Lindo, University of Southern California

AIAA Distinguished Lecturer Bevilaqua Speaks at Western Michigan University

The AIAA Western Michigan University Student Branch welcomed back **Dr. Paul Bevilaqua** for a second time to share his talk: Inventing the Joint Strike Fighter. Rather than sharing details on the F-35s performance and capabilities, the presentation largely focused on the design process from the early mission requirements from DARPA and the U.S. military up to final detail design and testing. This format was especially interesting for engineering students and faculty alike as this lecture provided real-world applications of the concepts and fundamentals covered in aerospace engineering curriculum. Several concepts ranging from lasers to individual turbines driving the lift fan were discussed. Eventually Dr. Bevilaqua's proposal of a shaft driven from the main engine to the lift fan was adopted by Lockheed Martin. Thermodynamic cycle analysis of the new propulsion system was also presented, which further reinforced concepts covered in undergraduate engineering courses.

AIAA Student Branch Chair Tyler Wall highly recommends the AIAA distinguished lecture program to other student chapters. Each year, the distinguished lecture manual available is updated and provides a list of speakers and processes to conduct one of these events. Student branches interested in taking advantage of this program should start the planning process early in the fall.

AIAA Delaware Section Participates in Mission: Space

The K–12 STEM Outreach Committee would like to recognize outstanding STEM events in each section. Each month we will highlight an outstanding K–12 STEM activity; if your section would like to be featured, please contact Supriya Banerjee (1Supriya.Banerjee@gmail.com) and Angela Diggs (Angela.Spence@gmail.com).

On 9 May, AIAA Fellow Dr. Mary "Missy" Cummings spoke at the opening reception of the new exhibit "Drones – Is the Sky the Limit?" at the Intrepid Sea, Air & Space Museum in New York City. AIAA is a sponsor of the exhibit, and Dr. Cummings, a professor at Duke University, was one of its primary curators. The UAV-focused exhibit will run through the end of the year. Find out more information about this exciting exhibit at intrepidmuseum.org.

When the AIAA Delaware Section heard about a program called Mission: Space occurring in its own backyard, the section knew it had to get involved. Bunker Hill Elementary School in Middletown, DE, started the program as an opportunity for its 4th and 5th grade students to use telescopes to examine the stars as part of their science unit on the night sky. The program grew to include all 4th and 5th grade students in the Appoquinimink School District. The students are not only using telescopes, but there are keynote speakers, hand-on activities and other exhibits for the students to explore, all designed to increase excitement and enthusiasm for space sciences.

This year was the first year the AIAA Delaware Section participated. Section Chair Breanne Sutton learned about the event at a STEM Mixer for the state of Delaware, and the section volunteered to host one of the hands-on activities, and Ms. Sutton was asked to be one of the keynote speakers. The planners were very excited to have a female keynote speaker for the STEM event.

On 24 January, over 500 students and parents attended the event at Appoquinimink High School. ILC Dover was in attendance with their display spacesuit, moon rocks were on loan from NASA, astronaut food was for sale, and the students could enter an inflatable planetarium set up in the gym. The AIAA Delaware Section hosted a planetary lander activity, which had detailed instructions, a supply list, and even an instructor worksheet available online (https://www.nasa.gov/pdf/418011main_OTM_Touchdown.pdf). The activity was so popular that the volunteers had to make a mid-activity run to the store for more supplies and set up more tables. The seven volunteers who staffed the activity were busy all night, with students still working to improve and test their landers as the program ended. The section plans to host an activity booth at future Mission: Space events, alternating between two activities so there is a new experience for students each year they attend.

Obituaries

AIAA Fellow Page Died in October 2016

Dr. Robert H. Page, 88, died 25 October 2016. A World War II veteran, Dr. Page enlisted in the U.S. Army and was sent to Virginia Military Institute and then to Armed Forces Radio Services for duty in Honolulu, HI. He received a B.S. in Mechanical Engineering from Ohio University in 1949 and an M.S./Ph.D. from University of Illinois in 1955.

Dr. Page held leadership positions with Esso Research and Engineering Company, as well as the University of Illinois and Stevens Institute of Technology. He was the head of the Department of Mechanical, Industrial, and Aerospace Engineering at Rutgers University for 15 years before becoming the Dean of Engineering at Texas A&M University and then held the James M. Forsyth Professor of Mechanical Engineering Endowed Chair until his retirement.

He gained international recognition for his research in flow separation analysis and its application to practical problems. He presented over 170 lectures and over 250 professional papers. Dr. Page was noted for his research and teaching on non-isoenergetic supersonic base flow, thermodynamic second law solution of subsonic base flow, and impingement jet flows. He thought his principal accomplishments were the development of strong, successful engineering education programs.

In 1984, he was honored as the first non-German scientist to be appointed an Honorary Professor at Ruhr University in Bochum, Germany. He was a fellow of the American Society of Mechanical Engineers, the American Society of Engineering Education (ASEE), AIAA, the Accreditation Board of Engineering and Technology, the American Astronautical Society, and the American Association for Advancement of Science. He was awarded the AIAA 50-year pin commemorating his contributions to the advancement of the arts, science, and technology of aeronautics and astronautics at Texas A&M and the Johnson Space Center.

AIAA Fellow Tischler Died in January

Adelbert O. "Del" Tischler passed away 12 January.

Mr. Tischler joined the National Advisory Committee for Aeronautics in 1942 at the Aircraft Engine Research Laboratory (AERL). Drafted into the U.S. Air Force, he was transferred back to the AERL laboratory (now NASA Glenn Research Center) to develop fuels of 150-octane rating for wartime aircraft piston engines.

In 1950, Tischler began work to eliminate "screaming" in liquid rocket combustion chambers. These investigations led to methods of limiting the problem in later engines. He also worked with others on design, building and operating rocket combustion chambers using liquid hydrogen as the rocket fuel, with oxygen and fluorine used as oxidizers. He was the safety officer at the research test site for these experimental operations.

In 1958 Tischler began work with other scientists and engineers to lay out a plan for U.S. space exploration. These working groups set forth most of the missions, equipment requirements and basic plans for NASA. Tischler was appointed Director of (Rocket) Propulsion Developments in NASA's Office of Manned Space Flight (OMSF). He was charged with initiating and developing the F-1, RL-10 and J-2 engines used on the Saturn series of vehicles. In 1960 solid propellant rocket technology was also assigned to his supervision.

He went on to serve as the Director of the Chemical Propulsion Division in the Office of Advanced Research and Technology (1964–1969). Tischler then served as the Director of the Shuttle Technology Office (1970–1972) and worked on several task forces aimed at finding more cost-effective methods for space operations prior to his retirement in 1973.

During the late 1970s and early 1980s Tischler was a consultant to the European Space Agency in the construction of the first reusable SpaceLab system and the follow-on job of generating the first SpaceLab payload. With Dr. Dah Yu Cheng, Tischler formed a company to develop gas turbine systems operating on a new cycle capable of achieving energy conversion efficiencies of fifty-eight. About 100 Cheng-cycle engines are presently in operation, generating electrical power around the world.

During the 1950s, Tischler served a term as president of the Cleveland-Akron Chapter of the American Rocket Society. He received the AIAA Wyld Propulsion Award in 1967. For his work on the Shuttle Technologies program he received NASA's Exceptional Service Award. He published over 60 reports and journal articles as well as many notes on several topics related to aerospace endeavors.

AIAA Fellow Nayfeh Died in March

Ali Nayfeh, a University Distinguished Professor Emeritus of the Virginia Polytechnic Institute and State University's (Virginia Tech) Department of Engineering Science and Mechanics, died on 27 March. He was 83.

Nayfeh earned all three of his academic degrees at Stanford University: a bachelor's degree in engineering science in 1962, and a master's degree and a Ph.D. in aeronautics and astronautics in 1963 and 1964, respectively.

Nayfeh joined the Virginia Tech community in 1971. He was a renowned teacher and researcher in the field of nonlinear dynamics. During his 37 years of teaching, Nayfeh advised 69 doctoral candidates to completion. He wrote 10 books, published over 400 articles in referred journals, and gave over 530 presentations at national and international conferences. From 1980 to 1984, Nayfeh took a leave of absence to establish an engineering college at Yarmouk University. He served as engineering dean of the college, and as vice-president for engineering affairs at the university.

His Wiley textbooks entitled *Perturbation Methods*, published in 1973, and *Introduction to Perturbation Techniques*, published in 1981, have been considered worldwide as premier reference texts on asymptotic methods over the past four decades. Nayfeh was also the founder of the two prestigious journals: *Nonlinear Dynamics* and the *Journal of Vibration*

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and Control. He also served as the editor of the Nonlinear Science Book Series.

Among his many honors were the 2014 Benjamin Franklin Medal in Mechanical Engineering, the 2008 Academy of Transdisciplinary Learning and Advanced Studies, the 2008 the American Society of Mechanical Engineers (ASME) Tom Caughey Award, the 2005 ASME Lyapunov Award, the 2005 Virginia's Life Achievement Award in Science, the 1996 ASME J. P. Den Hartog Award, and the 1981 Kuwait Prize in Basic Sciences. He was a Fellow of the American Academy of Mechanics, ASME, the American Physical Society, the Academy of Transdisciplinary Learning and Advanced Studies, and AIAA. In 1995, AIAA awarded Nayfeh the Pendray Aerospace Literature Award for his seminal contributions to perturbation methods, nonlinear dynamics, acoustics, and boundary-layer transition.

AIAA Associate Fellow Winker Died in April

James A. Winker, 88, died on 3 April.

Mr. Winker graduated from the University of Minnesota with degrees in Aeronautical Engineering and Business Administration. While in school, he worked part time at General Mills on their scientific balloon programs. In 1952, he joined General Mills and helped design scientific balloons and took part in a project that distributed pro-democracy leaflets behind the Iron Curtain.

Called into the U.S. Air Force in 1954, he was assigned to the balloon research group at the U.S. Air Force Cambridge Research Center in Bedford, MA, and attained the rank of Major. From 1956 until he retired as company vice president in 1991, he worked for Raven Industries, Inc., in Sioux Falls, SD. His achievements include assisting with the flight test of the first modern hot air balloon, designing high-altitude scientific balloons, and managing the manufacturing and sales of sport and scientific balloons.

He also worked with the FAA to develop hot air balloon regulations for the fledgling sport and became an FAA Balloon Pilot Examiner. He holds 13 balloon-related patents. After retiring, his historical research and archiving efforts lead to the creation of the Balloon Technology Collection currently managed by NASA.

During a lifetime involved in ballooning, Mr. Winker flew over the Swiss Alps in a gas balloon, served as an official at the first USSR International Balloon Championship, and launched an experimental balloon made from ancient materials over the Nazca Lines in Peru. He also flew his balloon, "My Blue Heaven," over the opening ceremony of the 1980 Lake Placid Olympics and attended all 21 World Hot Air Balloon Championships. In 2009, he was inducted into the U.S. National Ballooning Hall of Fame.

A long-time member of the AIAA Balloon Technical Committee, Mr. Winker received the 1999 AIAA Otto C. Winzen Award.

1917

June 2 The U.S. Army reorganizes its Aviation Section, calling it the Airplane Division, Army Signal Corps. On July 23, Maj. Benjamin Foulois is named its officer-in-charge. E.M. Emme, ed., **Aeronautics and Astronautics 1915-60**, p. 6.

June 13 The first mass airplane military operation occurs with a German raid on London. Charles Gibbs-Smith, **Aviation**, p. 247.

1942

June 3-5 The U.S. and Japanese navies fight the decisive Battle of Midway in the Central Pacific. Carrier-based U.S. Navy Douglas Dauntless dive bombers with Grumman F4F Wildcat fighter escorts destroy the Japanese aircraft carriers Akagi, Hiryu and Soryu as well as the cruiser Mikuma. The U.S. bombers also severely damage the carrier Kaga, and the Japanese eventually torpedo it. The Japanese also lose 250 aircraft. The Americans lose the aircraft carrier Yorktown and about 150 aircraft. The victory at Midway ends the Japanese offensive in the Pacific. **United States Naval Aviation 1910-1980**, pp. 115-116.

June 4 The Grumman TBF Avenger aircraft makes its wartime debut in the Battle of Midway, performing no better than the Douglas Devastators it's replacing. Five Avengers are shot down and one damaged beyond repair. Subsequent combat proves the Avenger to be a rugged and dependable torpedo bomber and horizontal bomber. Rene Francillon, **Grumman Aircraft Since 1929**, p. 176.

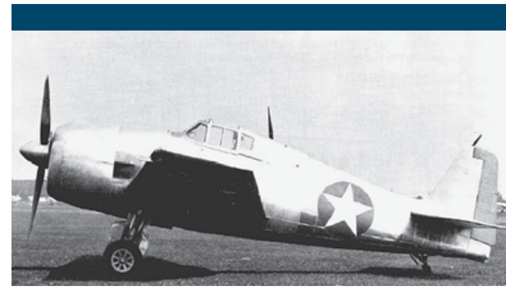
June 10 The U.S. Navy establishes Project Sail for the airborne testing of Magnetic Airborne Detectors, devices that locate submarines by the changes they induce in Earth's magnetic field. Navy airships and an Army Douglas B-18 carry the testing gear. **United States Naval Aviation 1910-1980**, p. 116.

June 12 A British Beaufighter aircraft flies over German-occupied Paris at midday and drops a French flag over the Arc de Triomphe. Another flag is dropped simultaneously in the Place de la Concorde. **The Aeroplane**, June 26, 1942, p.715.

June 13 Germany secretly launches the first A-4 rocket, later named V-2 (Vengeance Weapon 2), at Peenemünde, Germany. After a normal liftoff, the world's first large-scale liquid-propellant rocket rolls slightly about its axis, disappears into a dense cloud cover, then tumbles back out of control and crashes into the Baltic Sea, about 1 kilometer away from its starting point. The rocket does not have a successful flight until Oct. 3, when it travels nearly 200 kilometers. F.I. Ordway III and M.R. Sharpe, **The Rocket Team**, pp. 41-42.

June 13 A U.S. Navy K-2 airship carries LORAN (long-range navigation) equipment on its first airborne test during a flight from Naval Air Station Lakehurst, New Jersey. The military immediately adopts the device. **United States Naval Aviation 1910-1980**, p. 116.

June 17 The National Defense Research Committee starts to develop the Pelican anti-submarine guided missile, a glide bomb with a radar homing device. E.M. Emme, ed., **Aeronautics and Astronautics 1915-60**, p. 43.



June 26 The prototype of the Grumman F6F Hellcat makes its first flight and subsequently becomes one of the most important fighter aircraft of World War II. It becomes operational in August 1943 when it is flown from a U.S. aircraft carrier in the Pacific theater against Japanese targets on Marcus Island. Rene Francillon, **Grumman Aircraft Since 1929**, p. 206.

June 27 The Naval Aircraft Factory is directed to join the Army in developing high-altitude pressure flying suits. E.M. Emme, ed., **Aeronautics and Astronautics 1915-60**, p. 43.

June 30 Brig. Gen. James Doolittle wins the 1942 Guggenheim Medal "for notable achievements in the advancement of aeronautics." E.M. Emme, ed., **Aeronautics and Astronautics 1915-60**, p. 43.

1967

June 1 The first nonstop trans-Atlantic helicopter flights land at Le Bourget Airport, opposite the Paris 27th International Air and Space Show, following 30 hour, 46 minute flights from New York. U.S. Air Force Majs. Herbert Zehnder and Donald Maurras in their Air Force/Sikorsky HH-3E Sea Kings follow the same route taken by Charles Lindbergh when he made his solo airplane flight in 1927. During the 6,872-kilometer flights, each helicopter makes nine aerial refuelings. The refueling aircraft is the Lockheed HC-130P turboprop tanker. The HH-3E is the only helicopter designed for aerial refueling. The flights also achieve New York-to-Paris speed records. Helicopter pioneer Sergei Sikorsky greets the pilots upon their arrival at Le Bourget. **New York Times**, June 1, 1967, p. 17; **Aviation Week**, June 12, 1967, pp. 38-39.

June 2 Astronaut Edwin (Buzz) Aldrin receives the first honorary membership awarded by the International Association of Mechanics and Aerospace Workers. The group cites Aldrin for his work with tools outside the Gemini 12 spacecraft on Nov. 13, 1966, and calls him the "first space mechanic." **Houston Chronicle**, June 2, 1967.

June 3 Lloyd Berkner, a pioneer in the U.S. space program and hailed as the "father of the International Geophysical Year," dies of an apparent heart attack while attending a Washington, D.C., meeting at the National Academy of Science Council. Berkner was the principal administrator of the U.S. part of the International Geophysical Year, which ran from July 1, 1957, to Dec. 31, 1958, and included the U.S. Project Vanguard satellite launches. He also served as chairman of the council's Space Science Board and was a member of the NASA Historical Advisory Committee. **Washington Star**, June 5, 1967, p. B5.

June 5 Boeing delivers its 1,000th jet airliner since its first Boeing 707 was accepted by Pan American Airways in August 1958. The 1,000th aircraft is the 707-120B, delivered to American Airlines. **Air International**, June 15, 1967, p. 974.

June 5-10 Israel and six Arab states fight the Six-Day War. Israel's victory is credited to its airpower. When Egyptian forces mobilize along the Israeli border, Israel makes pre-emptive airstrikes against Egyptian airfields, destroying nearly the entire Egyptian air force with few Israeli losses. **Flight International**, June 29, 1967, pp. 1079-1080.

June 6 President Johnson appoints astronaut James Lovell Jr. as special consultant to the president for physical fitness, replacing retired St. Louis Cardinal baseball player Stan Musial. **NASA**, **Astronautics and Aeronautics, 1967**, p. 178.

June 8 Britain launches a new solid-propellant sounding rocket called the Petrel for the first time at the South Uist range in Scotland's Outer Hebrides. The low-cost rocket designed for scientific exploration of the Earth's environment can carry scientific payloads up to 135 kilometers. **Flight International**, June 18, 1967, p. 999.

June 12 and June 14 The Soviet Union launches its Venera 4 space probe toward Venus and two days later on June 14 the U.S. also takes advantage of the close opposition of the planet to launch its Mariner 5 to Venus. Venera 4 subsequently becomes the first probe to send data from another planet's atmosphere. Among other findings, the Soviet probe's chemical analysis shows the Venusian atmosphere is made up primarily of carbon dioxide. Mariner 5 measures interplanetary and Venusian magnetic fields, charged particles, plasma, radio refractivity and UV emissions of the atmosphere. **Aviation Week**, June 19, 1967, p. 24; **NASA Space Science Data Coordinated Archive**.

June 13 Sir Edward Ellington, one of the founders of the Royal Air Force and Marshall of the Royal Air Force, dies at 89. He learned to fly in 1912 while a captain in the Royal Artillery. When the RAF was formed in April 1918, he was transferred to the new service with the temporary rank of major general and helped organize the branch, which was the world's first independent air force. **Flight International**, June 22, 1967, p. 1006.

June 14 The Grumman TC-4C bombardier/navigator trainer, designed for the training of A-6A Intruder bombardier/navigators, makes its first flight at Bethpage, New York. **Flight International**, June 22, 1967, p. 1006.

June 17 The United States' most powerful 660-centimeter solid-propellant rocket motor, Aerojet's SL-3, is fired and delivers 222,451,067 newtons of thrust during its 80-second test conducted for NASA at Homestead, Florida. This is the third in NASA's Large Solid Rocket Technology Program, though this is the highest thrust yet reached. **Washington Post**, June 18, 1967, p. A2.

1992

June 10 Students from the Mississippi State University Raspet Flight Research Laboratory roll out a 50-foot-long mock-up of the proposed National Aero-Space Plane, known as the NASP. The students earned the chance to build the one-third scale plane in a competition. **NASA, Astronautics and Aeronautics, 1991-1995**, p. 216.

June 18 NASA and the Russian Space Agency for the first time ratify a contract, this one for a study to determine what Russian technologies could be used on the Space Station Freedom project. NASA's Daniel Goldin and the director general of the Russian Space Agency sign the documents. **NASA, Astronautics and Aeronautics, 1991-1995**, p. 216.

TIM HINERMAN, 33

Blue Origin, Deputy BE-4 Engine Lead

A lot is riding on upcoming tests of Blue Origin's BE-4 liquefied natural gas and liquid oxygen engine. In addition to powering the firm's future New Glenn orbital launch vehicle, the BE-4 is the leading contender for United Launch Alliance's next generation Vulcan launcher. If the tests later this year at Blue Origin's West Texas range prove its merit, the BE-4 could answer congressional calls for the U.S. to stop relying on Russian RD-180 engines for launches of military and intelligence community satellites on Atlas 5s. Blue Origin founder Jeff Bezos has also indicated that his 1,000-person company in Kent, Washington, could work with NASA to create a lunar cargo delivery service called Blue Moon.

How did you become an aerospace engineer?

Most people in the space industry say that their love of space came at an early age. For me, this wasn't the case. Growing up in a small town in Colorado, I didn't have opportunities to be exposed to space travel until I was a bit older. I always thought airplanes and rockets were neat, but they seemed so unattainable for me — and I was quite happy with my Tonka trucks at the time. As I got older, I decided I wanted to become an engineer. Cars always interested me, and I had a passion for internal combustion engines. This drove me to get a degree at Colorado State University because they had one of the best internal combustion engine programs in the country.

As my studies progressed, and my mind was opened, I began to see new avenues where I could apply my expertise. I switched my focus to aircraft, rockets and space — and was starting to finally become a space nut.

Now, I work at Blue Origin whose mission is to have millions of people living and working in space. Each step I have taken has led me to work for a company that is full of pioneers (and space nuts). I am proud to call myself one of them. In hindsight, my passion for cars and choice to study internal combustion was perfect because it's all about creating reliable systems, which is critical for reusability. To enable low-cost access to space, we need to create reusable launch systems, which is what I get the pleasure of doing every day at Blue Origin.

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

I am truly excited for the space flight revolution; a day when we make space truly accessible for everyone — just like aviation. It wasn't easy then, and it will not be easy now, but we need an incremental approach to make it happen.

My goal before I retire is to get space access to the point that the next generations of engineers will have to choose between optimizing space access or solving the next big technical problem. Just as engineers today focus on optimizing internal combustion engines, I want to see a future where engineers are optimizing space technologies that support the infrastructure of millions of people living and working in space.

By the end of my career, I want space access to be just as routine as aviation is today. Suborbital and low Earth orbit access should be a weekly, if not daily occurrence. Access to the moon, Mars and beyond should be within reach and we will be actively operating elsewhere in the solar system. ★

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