AEROSPACE AMERICA

TOMORROW'S BLACK BOXES

Should they be the same, ejectable or virtual?
We take you inside the debate.

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AIAA
SHAPING THE FUTURE OF AEROSPACE


Honeywell
FLIGHT RECORDER
DO NOT OPEN
Honeywell
FLIGHT RECORDER
SOLID STATE MEMORY COCKPIT VOICE RECORDER
SOLID STATE MEMORY FLIGHT DATA RECORDER
AC 31-30
BITE ATE (CAUTION: 115V)

AEROSPACE AMERICA

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SHAPING THE FUTURE OF AEROSPACE

IN THIS ISSUE

Keith Button

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

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Adam Hadhazy

Adam reports on astrophysics and technology. His work has appeared in Discover and New Scientist magazines.

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Tom Jones

Tom Jones flew on four space shuttle missions and is an adviser to the Coalition for Deep Space Exploration. He has a doctorate in planetary sciences.

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Jan Tegler

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

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Debra Werner

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

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DEPARTMENTS

Rethinking black boxes

All of us probably have one thing in our personal lives that tops the list of things we wish we didn't have to spend time or money on.

For the airline industry, black box technology has been that thing. Only modest improvements have been made over the years to these flight data and cockpit voice recorders, and yet over the same time span, wings gained winglets to reduce drag, engines became vastly quieter with larger front fans, and fuselages sprouted bumps to house antennas for satellite Wi-Fi.

▲ **This flight data** recorder was recovered from the crash site of West Air Sweden Flight 294, a Bombardier CRJ200 that went down in Sweden in 2016. Despite the heavy damage, data was retrieved.

Swedish Accident Investigation Authority

We've seen so much innovation, and yet when an airliner goes down over the water, we might as well be living in the 1960s. Microphones are dragged by ships or more lately by robotic craft to listen for acoustic pings from the underwater locator beacons on the boxes. In a surprisingly large number of cases, these boxes are never recovered.

Judging by this month's cover story, the seeds of change have been planted by the International Civil Aviation Organization. The question now is whether they will take root.

The story examines the possible technical solutions (ejectable boxes versus streaming data) and explores the resistance of airlines and regulators to making either of these a requirement. Money is probably a factor, as it almost always is in any industry, but it might not be the only factor. The industry has invested in tracking aircraft with greater fidelity than ever via satellite. In one view, this means there's no longer a need for a radical rethinking of the black box strategy.

Does the argument make sense? I'll let you be the judge.

Of course, the revolution could happen despite the resistance. The ejectable-box innovation is being rolled out on Airbus A350s XWBs even without a requirement. The streaming option has been slower to catch on.

No matter how this saga turns out, the innovations won't get us to our destinations faster or entertain us on a long trip. The best we can hope for is peace of mind that in the rare event of a crash, our loved ones won't have to suffer as the Malaysia Airlines Flight 370 families have.

Perhaps that is priceless. ★

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

Readers react

Examining the MAX

Our July/August article "Learning from the MAX" gave readers lots to think about. **Herbert "Skip" Hickey,** AIAA senior member emeritus, said that although the article was interesting, the pilots' lack of surprise in the depicted scenario did not "properly emulate the performance" of the Lion Air and Ethiopian Airlines crews.

"Since the cause of the loss of control was known beforehand, the proper commands from the captain to the first officer [in the article] were given precisely and unequivocally and did not follow procedures as given in the flight manual to wit, the throttles were moved to idle. This was not in the flight manual. This eased the recovery procedure by reducing the nose up pitching moment and decreasing speed. As pointed out in the article, speed is the enemy because the increase in elevator hinge moments could result in excessive control forces making recovery from a nose low attitude difficult. So the simulation was interesting, it showed recovery could possibly have been accomplished provided the pilots did not follow handbook procedures.

"However, airline pilots assume emergency procedures have been verified and validated and, therefore, follow procedures. The MCAS is an 'add on' to the stall identification system already in the 737NG. … Since the MCAS was an add on, it was assumed by Boeing that the recovery procedures as provided for the 737NG would suffice. Thus, the simulation could have highlighted shortcomings in the procedures due to the addition of MCAS and their order of accomplishment. This could have been revealing and instructive," wrote Hickey.

Others had a different take on the MAX story. For **Mike Helton**, a risk management expert and AIAA senior member, the article "relates the very tenuous boundary between a boring, ho-hum flight in a 737 MAX 8 airliner and one that suddenly goes unstable for the pilots, sending the aircraft into the ground at almost the speed of sound.

"It is rather obvious that the manufacturer does not have a process quality control system in the implementation of this aircraft. Reports on the continuing congressional hearings continue to expose other problems that were not considered before. A high-quality comprehensive set of processes at each phase with audit controls and standards would have picked up the many shortfalls in the design, development, testing and implementation of this vehicle. It might take a little longer and cost a little more up front, but today, we would have the MAX 8 flying and with a clean record."

Jet A fuel vs. batteries

After reading our June article "Flying electric," AIAA associate fellow **Thomas Brogan** doesn't think the story adequately emphasized the "really stark issue for an all-electric aircraft" of the comparative energy/mass between batteries and Jet A fuel.

"The energy density of state-of-the-art batteries is about one megajoule/kilogram (mj/kg). It has remained at or near that level for many years, in spite of plentiful motivation to improve it. The energy level of Jet A is 43 mj/kg. This is an enormous differential even given that only a fraction of the Jet A energy content is recovered as work. Moreover, unlike with batteries, the Jet A is burned off during flight, reducing the work required to power the airplane," wrote Brogan.

Accepting risk in aerospace

Frank Hurley, an AIAA associate fellow emeritus, thinks **AIAA Executive Director Dan Dumbacher** "hit the nail on the head" in his June Flight Path column, "Scar tissue," which calls for a balanced approach in determining what are acceptable

CONTINUED ON PAGE 6

Scan this QR code to read the complete letters online.

CORRECTIONS

• In the Looking Back | Mission Milestones section of the July/August issue, the time and date we listed for Neil Armstrong's first step on the moon should have been identified as Greenwich Mean Time, meaning 02:56 a.m. GMT on July 21, or 10:56 p.m. Eastern Time on July 20. GMT is the standard usage by NASA in stating times in spaceflight missions.

• In the article "Learning from the MAX" in the July/August issue, there was an incorrect description of the action taken by the airliner pilot if the nose of the aircraft pitches down. It should have said that the captain or pilot flying will disconnect the autopilot and auto throttle, not command the first officer to do it. Then it is presumed that the pilot flying is too busy to reach down to turn off the stab trim cutout switches, so he commands the first officer to do it.

risks in technology development. As deputy chief scientist at NASA Headquarters in 1984, Hurley remembers the negative reactions he got to a suggestion of extending flight demonstrations for a remotely piloted experimental aircraft at NASA's Dryden Flight Research Center in California [now NASA Armstrong].

"If our flight research (Dryden's middle name!) isn't scattering some debris across the Mojave Desert, we're not trying hard enough. Yet, fear of failure rather than lust for success had ruled. By the way, I'm blaming NASA's culture rather than its leadership for this, as an excellent team occupied the administrator's office at that moment in history. Perhaps our engineers and managers could be more aggressive if some really gifted spinmeisters from the political world were protecting them. Here's a sample press release: 'NASA is pleased to announce that the ____ unmanned flight research vehicle has been tested to destruction, AS PLANNED, to capture data that will enable confident design of the Air Force's ______ combat aircraft,'" wrote Hurley.

Modifying us for living in deep space

"Thanks for carrying the article 'Homo sapiens astronauta' [July/August]," AIAA senior member **Michael Michaud** emailed. "It is a fascinating look at future possibilities, well presented by Adam Hadhazy."

Apollo 11 and risk

Reading our special section about the Apollo 11 anniversary, Robert J. Wetherall, an AIAA associate fellow and a program manager at Lockheed Martin Aeronautics, found "Curb your disillusionment" by Samantha Walters "honest, enlightening and telling, especially with regard to risk management." He writes that with the advent of computer-aided design, manufacturing and simulation in the 1980s and 1990s, "an environment was created where taking risk in testing could prove embarrassing and costly, so the industry retrenched to the point where major systems can now take decades, not years to develop.

"Unfortunately, today's industry views any failure as a significant setback, many times resulting in the end of a program or effort, which can be very damaging to the nation. A recent example is the Falcon HTV-2, which, after two imperfect but very valuable flight tests, was terminated. Shortly thereafter, we discovered that our adversaries (who had started or advanced their own hypersonics programs as a direct result of our Falcon HTV-2 effort) moved significantly ahead of us, and as a result our nation now finds itself playing catch-up. This was brought into clear focus in a quote from a Washington Post

NASA

article attributed to U.S. Air Force Gen. John Hyten, commander of U.S. Strategic Command, 'We had a couple of failures [with the HTV-2], so we kind of stopped and regrouped to look at the overall structure, to make sure we understood the technology — what was working, what was not working. From my perspective, I'd have liked to have just learned from that mistake and kept going. Don't stop.' To me he's saying, 'Let's do what Apollo did … learn from the failures and continue toward the goal.'

"We understand that Cold War tensions fueled our commitment to Apollo. But that incredible program showed us what we can accomplish when we do commit ourselves to a goal, no matter the reason, and no matter the cost. I would hope that as a nation, and as a planet, that we can make similar commitments going forward, not out of fear but out of a desire to accomplish those goals that depend more on commitment and balanced risk-taking than about anything else."

Also in reaction to our Apollo 11 anniversary section, **Eli Gai**, an AIAA fellow and former vice president for engineering at Draper noted the contribution of Draper Instrumentation Laboratory, then the MIT Instrumentation Laboratory, in navigation for Apollo 11.

"The instrumentation lab got the first Apollo contract on a sole source basis to design the guidance, navigation control and computer for the mission. They got it because NASA was reluctant to use radio navigation, suspecting that the Soviet Union will jam the system if they fall behind. The instrumentation lab proposed a self-contained inertial navigation system similar to the one they designed for the Polaris missile. The Apollo guidance computer that used integrated circuits was the beginning of the digital era," wrote Gai. ★

Creating the Future

Photo credit: Boeing

***Imagine this:** You've had a busier than expected day at the office, and before you know it, you're running late to catch a long flight. To make matters worse, it's rush hour and there's just not enough time to drive to the airport or take the subway. But not to worry: PAV (Passenger Air Vehicle) Service just came online in your city. You order your ride, walk a block to the nearest staging area, and within minutes, you're on your way.*

The PAV gently and quietly cruises toward the airport as you take in a panoramic view of the city skyline, taking note of the standstill traffic below. Before you realize it, you've arrived—and to your delight, there's still plenty of time to make your flight.

The Future is Now

This sounds impossibly futuristic, but work is in progress now to make this a reality within the next decade. The benefits go far beyond getting to the airport in record time. In the same way that commercial air travel has connected continents and made the world smaller, PAVs and other intelligent systems will shrink the distance between cities and regions—completely redefining how and where people live, work, and play. Imagine the freedom of living in the mountains *and* working in the city. Imagine the economic benefits for small towns with a lot to offer visitors but no connectivity to mass transit infrastructure. Imagine a world where rush-hour traffic is no more, and online orders arrive at your doorstep, directly from the factory, within minutes. *This will change everything.*

Challenges

But this future will not arrive on its own. Three broad trends driving aerospace today create significant challenges we must overcome:

First, physical and computational integration of flight vehicle systems is becoming increasingly key for performance, capability, and cost. Consider the case of PAV, where sensor fusion will enable software to make real-time decisions in a way that is safe, reliable, and certifiable; and where data fusion for operations will allow ground operations to effectively control a fleet of PAVs—ensuring passenger safety and comfort. Vertically integrated business structures will unlock the economies of scale needed to achieve a new feat for humankind—the production of aircraft grade vehicles at automotive rates.

Second, aerospace technologies are proliferating faster than ever before. We can see this democratization of technology in the drone revolution, for example, where unmanned systems have evolved to higher levels of autonomy. These intelligent systems have *increased* the number of pilots as piloting small aircraft has become more accessible, and in the same way these systems hold promise to play a role in solving the expected pilot shortage the industry faces in the future. This proliferation has brought increased competition from nontraditional players, and a heightened need to harden intelligent systems against emerging, sophisticated international threats that include state and non-state actors who see potential for public harm in these technological advances.

Third, we must attract talent. As the skills demanded by the transportation industry evolve, aerospace in particular will compete more intensely with the automotive sector and more directly with the technology sector for talent. We must work with the educational system to realign graduates' skillsets with the new requirements of our industry, and work with our existing talent pools to reskill our industry's labor force for the needs of the near future.

AIAA's Role

We have been successful in the past as we, along with the rest of the industry, organized around aerospace's traditional "Breguet Disciplines" of aero, structures, and propulsion. Leadership has been trained on these classical disciplines and most engineering organizations are built around them. But in order to attract talent and meet the demands of the next generation of mobility, we must lead the industry in reorganizing around the more nascent disciplines of intelligent systems, which include artificial intelligence, robotics, sensors and perception, human–machine interaction, statistics, data analytics, and cyberphysical security. AIAA must become better equipped to serve these professionals, and encourage the market as it establishes, certifies, and grows core competencies in intelligent systems disciplines all along the value chain.

The greatest generation put man on the moon. The next generation may get us to Mars. We can play a vital role in enabling this generation to create this future, but only if we act decisively.

Let us begin that work today, and together discover the untold future of tomorrow. ★

John Langford, AIAA President

AERO PUZZLER

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

Pigskin preview

Q. Nineteenth-century British inventor William Hale and your favorite football quarterback have something in common. What is it?

Draft a response of no more than 250 words and email it by midnight Eastern time on Sept. 9 to aeropuzzler@aiaa.org.

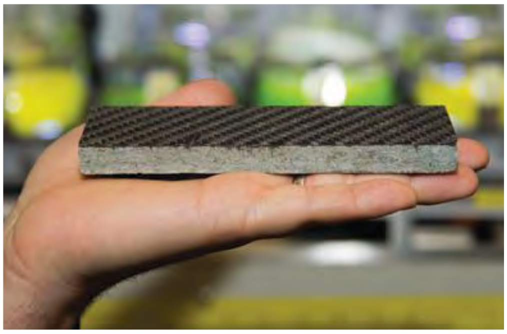
FROM THE JULY/AUGUST ISSUE

FLYING INVERTED: We asked you whether Capt. Whip Whitaker's decision to invert his airliner in the movie "Flight" would be worth a shot in a real-world emergency.

FROM THE EDITORS: We agreed with reviewer Mark Guynn of NASA's Langley Research Center in Virginia that none of your responses fully addressed the question, and we take responsibility for that. In hindsight, we should have asked why inverting an actual airliner likely would or would not increase odds of surviving a nose-down emergency. We expected your responses to analyze the crash of Alaska Airlines 261 in which the captain and first officer inverted their MD-83 to buy time to fight its uncommanded nose-down pitch, but could not retain control. The captain voiced, "gotta get it over again ... at least upside down we're flying." Within seconds, the engines were heard stalling and spooling down, and the plane crashed into the Pacific Ocean, killing all 88 aboard. While there is no definitive right or wrong answer, this outcome suggests to us that inverting an airliner probably would not improve odds of survival.

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

Researchers grow algae at the Technical University of Munich's AlgaeTec facility in Ottobrunn, Germany. Below, a granite plate reinforced with carbon fiber derived from algae.
Technical University of Munich



Aircraft from algae

BY ADAM HADHAZY | adamhadhazy@gmail.com

Goopy algae and the composite structures in aircraft seem about as unalike as it gets, but they are in fact coming together.

In a project dubbed Green Carbon, researchers in Germany are investigating how to economically derive oil from algae as a step toward producing carbon fibers that would otherwise be made from the carbon in petroleum.

The researchers have so far made small batches of fiber and turned them into composite material by the normal method of weaving them into a fabric and wetting it with resin plus a hardening agent. The task now is to scale up the cultivation of algae and the manufacturing.

The aerospace industry loves composites. Half the airframe of each Boeing 787 Dreamliner is constructed of petroleum-derived composites, and those parts weight 20% less than if they were made from aluminum. The Airbus A350 XWB likewise incorporates carbon fiber in its fuselage and wings.

The downside of composites has been their carbon footprints, and that's the problem TUM, for the Technical University of Munich in Germany, and Airbus aim to solve.

Algae could flip this carbonaceous script. These unicellular organisms pull carbon from the atmosphere and incorporate it into triglycerides — fatty molecules that contain a backbone of glycerol. The researchers have chemically cleaved off this glycerol and turned it into polyacrylonitrile fibers, called PAN. Charring PAN at around 2,000 degrees Celsius in a solar-powered oven yields carbon fibers, says project lead Thomas Brück, a professor of synthetic biotechnology at TUM.

Algae offer advantages over other bio sources. They grow 10 times faster than plants, Brück says, while accumulating 40 times more useful lipids (oil) per hectare of cultivation. They need vats of wastewater or seawater rather than arable land. "Therefore," says Brück, the algae "do not compete" with food crops. In the U.S., about 40% of the corn yield is made into ethanol.

At TUM's AlgaeTec facility, built in 2015 in Ottobrunn, Germany, researchers are determining the optimal lighting and climate for one algal species of particular interest, Microchloropsis salina. The TUM team is considering a region in the south of Spain for a first demonstration plant.

Beyond making carbon fiber composite materials like those in the 787, researchers are also mating carbon fiber with granite. This fiber-plus-rock material combo is lighter than standard aluminum, several times stronger than steel, and obviates plastics derived from fossil fuels.

Before you see JetBlue relaunch itself as JetGreen, more work lies ahead for Green Carbon. "We cannot build an entire airplane yet," says Brück. Before graduating to major components such as the airframe, some early applications of the algae-grown fibers paired with granite could be aircraft floors and armrests. Brück says discussions are also ongoing with project partner Airbus about the material's potential in small autonomous or personal flight vehicles.

Overall, the Green Carbon effort is showing potential for building carbon-neutral or maybe carbon-negative aircraft that would remove more carbon from the atmosphere than they put in. Says Brück: "We hope that this vision will become reality with our materials." ★

Airbus

Visionary leadership

Mark Cousin's staff must create the technologies that will propel Airbus into the future of flight. If all goes as planned, digitally manufactured autonomous aircraft will shuttle passengers quietly and cleanly through a well-organized airspace. This must be true whether passengers are riding in small urban air mobility craft or in airliners. Cousin is head of A^3, pronounced "A cubed," the DARPA-inspired innovation center that Airbus established in 2015 in California's Silicon Valley. I interviewed Cousin in June at the AIAA Aviation Forum in Dallas.

— *Ben Iannotta*

MARK COUSIN

POSITIONS: CEO of A^3 by Airbus since December 2018; head of flight demonstrators in Airbus' Chief Technology Office organization and CEO of ExO Alpha, the company's research and technology subsidiary, 2016-2018.

NOTABLE: From 2015 to 2016, led the design and manufacturing of the Beluga XL cargo jet that is scheduled to start carrying A350 parts between Airbus facilities later this year. He is the third CEO of A^3 by Airbus since the center's founding in 2015. Cousin joined Airbus in 1998.

AGE: 54

RESIDENCE: Sunnyvale, California

EDUCATION: Bachelor of Science in aeronautics and astronautics from the University of Southampton in England, 1986.

Scan this QR code to read the complete transcript online.

IN HIS WORDS

Parallel development

What we're trying to do in A³ is put to one side the traditional approach of developing technology until it's mature and then building the demonstrator. We turn that on its head and say, "OK, let's set an aggressive goal to build the demonstrator of something that we think is possible but develop the technology while we're developing the project." We do make our projects really time limited, so typically two to three years as a maximum to actually build and develop a sort of minimum viable product of something groundbreaking, something disruptive. We don't expect all of our projects to be successful.

Learning from success and failure

I would say we would expect at least 50% of our projects to actually transition into something useful, something meaningful for one of the business units of our company. We try to make sure now that all of the projects we run have some serious sponsorship within the business, so we're not just doing stuff that's cool; we're doing stuff that's cool but has some potential impact and support within the business. And I think in the first four years we've achieved about that. You know we've had some projects which have been very successful and have spawned in fact a new division within Airbus called Urban Air Mobility. And we've had some other projects which have not been successful in the traditional sense, but I think one of the things we've also learned is that you very often learn as much from failure as you do from success.

Urban air management

We have a big project, which is part of this urban air mobility push for urban traffic management, which will be absolutely critical once we have hundreds or even thousands of vehicles flying in the skies. We'll need a completely new means of controlling the low altitude airspace above cities. For example, typically in São Paulo today, we can have only six helicopters operational in the air at the same time. So the future requires not six, maybe 600 or even 6,000 vehicles airborne.

Flying clean on battery power

We have a very, very clear view from the cities that we've engaged with that these vehicles will have to be completely emissions free, otherwise they won't be welcome in modern cities where pollution is a major issue. With what I see today on the development of battery technology, I'm pretty optimistic, in fact, very optimistic, that the level of performance that we require to make these vehicles viable will be achieved within the next two or three years. The only real question is whether it will limit how big you can make the vehicle, how many passengers it can carry, or how far it can fly. But the technology is already very close to where we need it to be. And there is a huge amount of research going into battery development.

Automation vs. autonomy

The business case for urban air mobility doesn't work if those vehicles are not autonomous at some point in the future. If they have to be piloted, then the business case doesn't close. Also in our civil aircraft business, we know we have to move toward more autonomous aircraft. I draw a big distinction here between automation and autonomy. What we've done to date in aerospace is automate a lot of tasks. Autonomy is something very different. Autonomy means that the vehicle is making decisions and learning from its own mistakes. So we recognize that if we want the commercial aerospace business to continue growing as it is today — and it's predicted to double in size — we will not be able to do that if we continue with two or even four pilots in the cockpit.

Replicating a human pilot

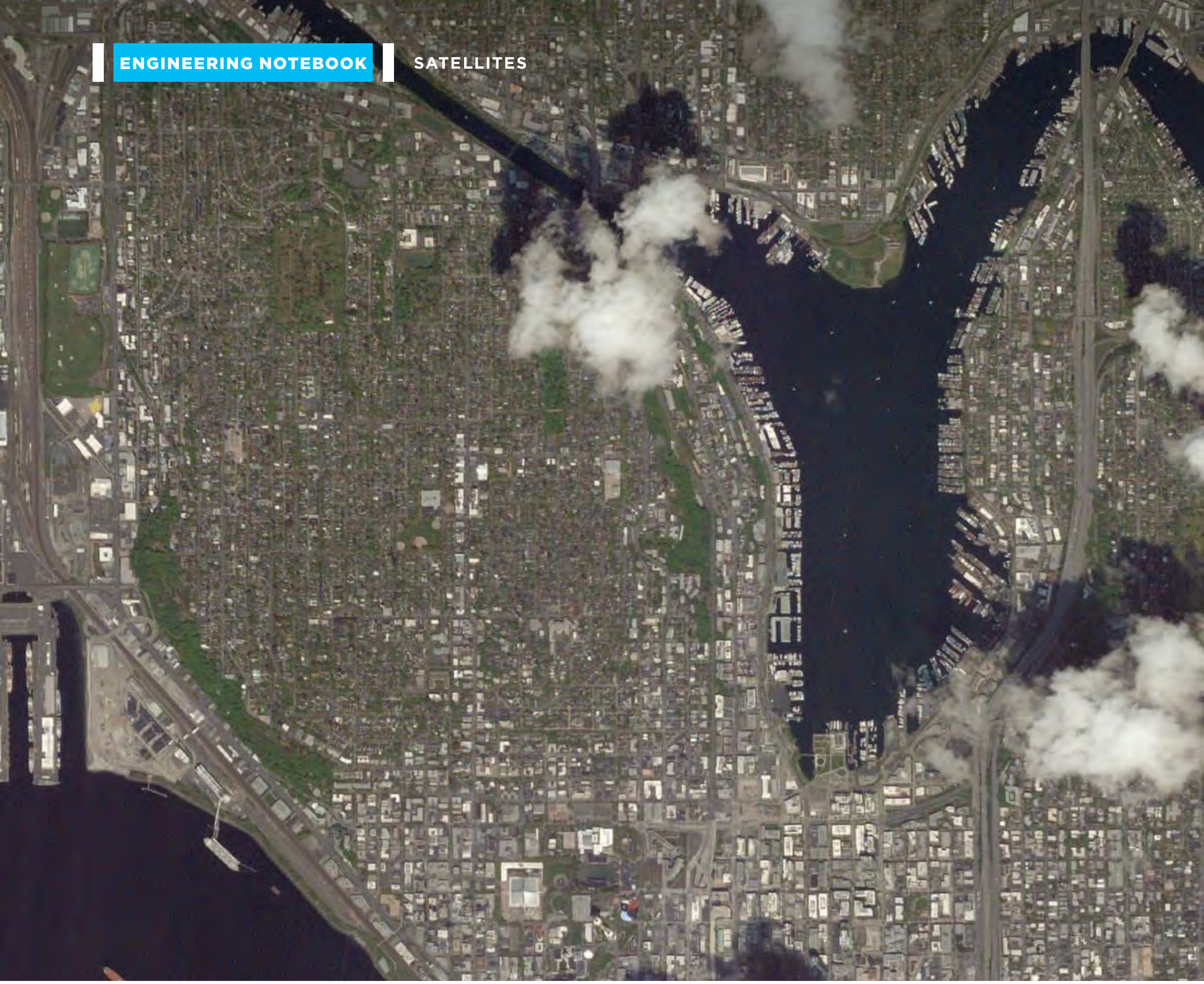
If you want to land an aircraft at an airport that's not equipped with sophisticated instrument landing systems, that's something that's done very well by a human pilot today. We're in the process of developing the ability to do that with an automated system, but that's quite difficult because you're doing that with a high-definition camera. It has to identify the runway, has to identify the touchdown point, has to fly the approach as a human pilot would. We're really on the edge of both sensing capability and computing capability to reproduce what a human pilot can do. On the other side, one of the huge potential benefits of machine learning is that if you think about incidents or even accidents that occur today with an aircraft, the only person who learns is the pilot in that particular flight. If you have an autonomous vehicle where the software is learning, then every single aircraft in the fleet will learn from every single event or occurrence. We need to be able to have a system which is able to start taking decisions when things don't go as planned, and project Wayfinder is really charting uncharted territory.

The coming pilot shortage

Our objective is to move toward commercial aircraft with a single pilot onboard. That's largely driven by the fact that if we extrapolate the growth of aviation today, then we will need to train 600,000 pilots in the next 20 years. Put that into context: We've only trained 200,000 pilots since the start of commercial aviation. So we know if we don't do something, the growth of the industry is going to be constrained by the availability of pilots. Now if you want to go to an aircraft with a single pilot onboard, you basically need to design an autonomous vehicle where the vehicle is going to take all of the decisions on what it should do, even in failure cases, and the crew member onboard is really there as performing the role that the pilot nonflying in the cockpit today would be performing. So there'd still be a human being onboard to intervene in extreme situations, but the vehicle or the architecture of the vehicle really has to be designed around an autonomous vehicle, which is a major departure from what we design today where we have a lot of automation but no real autonomy.

Certification complication for machine learning

Today we certify flight control software, which is fixed; it doesn't change. If we now want to certify something which is going to evolve with time, it's a different challenge. So certifiable autonomy is something which is really a major challenge and something which we're putting a lot of effort into.



Fine resolution from small satellites

For decades, it seemed like the only way to deliver detailed pictures of Earth from space was to orbit large telescopes and point them back at us. Today, companies are upending this conventional wisdom. Debra Werner looks at how one company, BlackSky, aims to storm the commercial imagery market.

BY DEBRA WERNER | werner.debra@gmail.com

▲ **A BlackSky Global** satellite image of Seattle.
BlackSky

Ikonos, the first commercial satellite to image Earth in submeter resolution, was about the size of two luxury refrigerators, whereas the Global satellites flown by BlackSky are the size of a dorm-room fridge. Yet images from Ikonos and these newer satellites are of comparable resolution, 82 centimeters in the case of Ikonos and 1 meter for the Global satellites. The images are sharp enough to detect changes in the terrain and the details of human-made structures and vehicles. Before Ikonos reached orbit in 1999, this resolution was strictly the purview of government spy satellites.

How is it possible that a Global satellite a fraction of the size of Ikonos can deliver images of about the same resolution and on top of that in color rather than black and white? BlackSky, the subsidiary of Seattle launch broker Spaceflight Industries, won't say exactly for fear of tipping off competitors in the hot commercial imagery market for sales to Fortune 500 companies, the U.S. National Reconnaissance Office and others.

But engineers involved with the project agreed to discuss the broad outlines of their strategy, which centered on tying together a host of small technical improvements that would wring maximum value from the photons entering each satellite's telescope. In areas they could not discuss, I spoke to outside experts to glean some informed speculation based on industry trends.

What's certain is that the BlackSky strategy is starting to be put to the test. The company has begun serving customers with three Global satellites in orbit, and a fourth was poised for launch by the end of August. An initial constellation of eight satellites should be in place by the end of the year.

As for the engineering strategy, "It's not magic. It's just very deliberate systems engineering and technology insertion," says Nick Merski, a systems engineer and operations vice president for Spaceflight Industries.

Specifically, engineers tied together advances in optics and detector materials to deliver a high signal-to-noise ratio and excellent modulation transfer function, a measure of an optical system's ability to show contrast within an image. These measures are among the keys to delivering fine resolution.

The quest began with an optical challenge. Ikonos gathered photons with a 70-cm primary mirror, but the optics on the BlackSky satellites needed to be a fraction of that size. By keeping the design small, the company could take advantage of lower launch costs and miniature electronics and offer customers an inexpensive way to obtain multiple daily views of the same locations on the ground.

BlackSky chose L3 Harris Technologies Intelligence, Surveillance, and Reconnaissance, or ISR, for the job of making the telescope. Based in Rochester, New York, this is the former Eastman Kodak satellite group that built the Ikonos telescope.

As groundbreaking as Ikonos was, engineers at the ISR group were among the first to see the potential for making imaging satellites smaller and lighter. The trend started about five years ago, and there's been an almost "exponential movement toward smaller," says Murali Krishnan, vice president and general manager of the ISR group.

Saving weight with composites

For decades, the assumption in the Earth-imaging business had been that satellites needed to be relatively large (at least Ikonos-sized) to gather enough photons to produce fine-resolution images. The only way to improve the resolution, the thinking went, was to orbit a larger aperture telescope or fly the satellite at a lower altitude to intercept the reflected sunlight closer to the source, before the photons diffuse very much.

In reality, a host of factors determine image resolution, chief among them being how many photons reach the detector material and how sensitive those detectors are. Detectors are now 10 times more effective than they were when Ikonos was built, says imagery expert Lars Dyrud, founder of OmniEarth, a small satellite imagery company acquired in 2017 by EagleView, a Bothell, Washington, aerial imagery company.

To save weight without sacrificing performance, engineers at the ISR group decided to make the mirrors out of composite materials, although for proprietary reasons they won't say how they manage to craft those materials into mirrors that reflect light with the required fidelity. The strategy reduced the weight and volume of the mirrors and shortened the production time.

L3 Harris declines to say whether it employed its patented processes for additively manufacturing mirrors by depositing successive layers of lightweight, elastic substances that resist thermal expansion. The materials include silicon carbides, carbon nanotube-filled polymeric materials and glass-ceramics. Once 3D printed, mirror cores are bonded to faceplates before the faceplates are finished with a multilayer reflective coating.

The engineers also set about shortening the length of the telescope cylinder. Again, the engineers need to avoid divulging exactly how this was done, but given trends elsewhere in the industry, they may have employed optical folding. Instead of mounting lenses at each end of a long tube, telescopes produce similarly long optical pathways by bouncing light off mirrors several times within the body of a shorter, wider telescope before it hits the detector. "You can take what would have been a 2- or 3-meter [long] telescope and scrunch it down to something like half a meter," says Dyrud.

The ISR group's technologies were put to the test in 2016, when BlackSky flew two "pathfinder satellites," each carrying a 24-cm-diameter primary mirror inside the SpaceView 24 telescope. The new telescopes were notable for their diminutive weight of 10 kilograms, compared to 171 kg for the Ikonos telescope.

The tests went well, judging by the fact that BlackSky's first four Global satellites, the three in orbit and one set to launch in August, are equipped with SpaceView telescopes.

> "Any error, be it vibrational jitter or tracking error, shows up as blur. If the tracking error is large enough, then you may miss the imaging target entirely."
>
> **— Andrew Maurer, Honeybee Robotics engineering director**

Pointing the telescope

Reducing size and weight was only part of the challenge. A great telescope won't yield high-resolution images unless it remains focused on a precise point on the ground as it zooms over at 28,000 kph.

This issue looms especially large for a small satellite, because imagers must typically be mounted directly to the spacecraft body to save mass and volume. If the satellite weighed hundreds of kilograms, it could be mounted on a platform that would isolate it from vibration. Without that possibility, the satellite itself must be steered for precise pointing, says Andrew Maurer, Honeybee Robotics engineering director. Honeybee does not work with BlackSky, but the company works with many Earth observation companies that need help pointing satellite imagers and other instruments.

BlackSky would not tell me how it addresses this pointing problem, but Maurer says there are two choices: reaction wheels or control moment gyroscopes. Reaction wheels are a simple and reliable way to fine-tune satellite pointing, but they typically can't produce enough torque to rapidly reorient the spacecraft toward new targets. That ultimately limits the number of images a spacecraft can produce per hour, Maurer says.

Control moment gyroscopes, on the other hand, offer enough torque to rapidly turn toward new targets, but they add complexity with two sets of motors and bearings, and optical encoders. What's

▼ **Global-1 and Global-2** satellites at the BlackSky facility.
BlackSky

▲ **An illustration of** the deployed Ikonos-2 satellite.
Lockheed Martin

more, control moment gyroscopes powerful enough for rapid repointing will struggle to produce the minuscule degree of torque required to keep a telescope pointed at its target. If the telescope drifts and then reacquires the target, the raw image comes out blurry.

In fact, "any error, be it vibrational jitter or tracking error, shows up as blur," Maurer says. "If the tracking error is large enough, then you may miss the imaging target entirely.

"That problem is something we work a lot for imaging customers in particular," he says.

With either approach, if the components are not balanced properly it can degrade satellite imagery.

"In these small spacecraft, you start to bump up against how well humankind can achieve that balance," Maurer says.

That's when processing comes in. Keep in mind these are not images captured on film, says Merski, the operations vice president at Space Industries. "They are ones and zeros that require processing to translate into pixels."

With software techniques like computer vision, which seeks to automate human visual processing, it's possible to work around the limitations of a particular sensor, says Scott Herman, BlackSky chief technology officer.

Processing images

BlackSky customers buy imagery for two main purposes: literal interpretation, in which terrain changes or other information is extracted through analysis, and electromagnetic radiometry, in which the precise intensities of reflected sunlight in various bands are measured. For customers seeking to measure electromagnetic radiation, "you would never manipulate the raw product," Merski says, referring to the picture elements that form an image. "But for improving interpretability, there are image processing techniques to improve contrast and sharpness."

Merski and Herman won't say exactly what BlackSky does with the software for fear competitors will gain valuable insight. Patents from other Earth-imaging companies reveal some of these techniques. Companies have created algorithms to amplify specific image details and correct for variation in lighting conditions. In one common application, processors align each color image frame with higher-resolution panchromatic views of the same area. Once aligned, objects on the ground like ships or planes that stand out in panchromatic frames can be sharpened in color pictures. Many satellite sensors also capture overlapping scenes, and computer processors then create detailed mosaics.

"It's very common for Earth-imaging companies to bring in the information from multiple images to create a composite image that has better resolution and better dynamic range than any one of the originals," Dyrud says.

BlackSky's standard image products at 1-meter resolution do not rely on this layering technique, but customers can request it to enhance imagery, Merski says.

Euroconsult, a space consulting firm based in Paris, predicts the market for Earth observation data drawn from satellites will grow from $1.7 billion in 2017 to $2.4 billion in 2027. And that's just for imagery.

Value-added services, like crop forecasts, that interpret the imagery could be a $9 billion market, Euroconsult says in "Satellite-Based Earth Observation: Market Prospects to 2027," a report published in October 2018.

So it's not surprising BlackSky and the ISR group are reluctant to share too many details. "A lot of people are exploring how to capture this market," Merski says. "People are looking at building architectures like ours. ★

The necessity of returning to the moon

A spacecraft lifts off from the moon with astronauts returning to the Gateway space station (not shown in this artist's rendering).
NASA

For 50 years, Americans have taken the moon for granted. Planetary scientist and former astronaut Tom Jones argues that returning there soon is an essential step toward other worlds, and continued leadership on this one.

BY TOM JONES | skywalking1@gmail.com
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The moon won't wait for us. Last January, China delivered its second probe, Chang'e-4, to the lunar surface — this time to the moon's far side. The fact that the spacecraft carried a rover to the surface reveals the design as an evolutionary step toward a lander that one day will carry taikonauts.

Given China's publicly stated lunar plans and all the moon has to teach us about traveling to more distant destinations, the U.S. Congress should approve the Trump administration's request for supplemental 2020 funding for NASA's proposed 2024 lunar return program, called Artemis.

The benefits of Artemis are many

This NASA-led effort is long overdue. That Americans have not returned to the moon's surface or even orbited it since 1972 is a national embarrassment. Returning to this resource-rich training ground is a vital stepping stone toward interplanetary space — toward the nearby asteroids and Mars. If America can lead a public-private partnership operating on the moon and beyond, we will benefit from new technologies, help protect our national security, boost our economic competitiveness, and inspire millions of young people toward careers in science, technology, engineering and math. We also will rebuild confidence in our society's ability to meet its most difficult challenges.

When Apollo 11 reached the moon 50 years ago, it gave the nation a long-lasting technological edge that contributed directly to winning the Cold War. It's a lead we have never relinquished but one now in jeopardy as China expands its space ambitions. Revitalizing our human exploration of deep space, to the moon and beyond, will stand as evidence of America's commitment to technological leadership.

Staying ahead

Today our leading position in space is precarious at best. The International Space Station, our current symbol of American-led space achievement, has only a decade of life remaining. Meanwhile, China plans to launch its next space station in 2020, and European Space Agency astronauts are learning Chinese with an eye toward joint missions aboard that outpost. China has announced plans to send human explorers to the moon by about 2030. When taikonauts do plant their flag there — and Chang'e-4 shows they are certainly on track to do it — the U.S. had better be there, too. Our absence on the moon will demonstrate to the world that America's technological and military abilities are second-rate, with observant nations aligning themselves with an autocratic yet confident superpower.

Given the usual lead time to develop and test rockets and spacecraft capable of reaching the moon,

▲ **The Orion crew module** for the Artemis-1 mission undergoes an acoustics test at Kennedy Space Center. Artemis-1 will send an uncrewed Orion into lunar orbit and return it to Earth.
NASA

we must decide now whether to lead an international and commercial partnership to return there or become an also-ran, a footnote in the still-unfolding saga of space exploration.

The White House recognizes this urgency. Its March announcement of a lunar return was followed by a May request for additional NASA funding for the program. NASA has since published its first technical outline of how to accomplish the goal by 2024.

To make that deadline, NASA must have its Orion deep space transport ready when its powerful but long-delayed booster, the Space Launch System, flies for the first time in early 2021. In parallel, NASA has already begun procurement of the power and propulsion element of the lunar-orbiting Gateway, which will be launched in 2022-2023 on a NASA-purchased commercial launch vehicle. This element, along with a small Northrop Grumman-built habitat, will form the minimalist Gateway that, with Orion and SLS, will support a lunar return. The final piece of the 2024 puzzle will be an industry-designed lunar lander, with NASA choosing among at least two competitive bidders, which are expected to contribute at least 10% of the development costs.

It's up to Congress

The 2024 goal will be a difficult challenge for NASA and industry, but it can be met, if the agency and industry receive the necessary resources. The numbers show that NASA's budget has steadily lost buying power for at least 20 years, with the agency's share of the federal budget similarly dropping from 0.8% to 0.47% (it peaked at 4.4% during Apollo). Yet that eroding budget had to operate the space shuttle, construct the ISS, and engineer new deep space vehicles and technologies. The deep space task has suffered for too long, repeatedly postponing human exploration beyond Earth.

Bold plans must be matched by necessary resources, a task that now falls squarely on the shoulders of Congress. With a 10% increase in NASA's budget — about $2 billion sustained for five years — we will not merely repeat Apollo's brief lunar visits, but build instead a sustainable, reusable lunar transportation system. That hardware will enable us to stay and explore the moon longer, harness its resources and, through reuse, prove the machines and skills we will need for Mars.

Clear goal

The 2024 deadline is key to our return to the moon. The challenge is not developing the technologies of getting to the moon and back — the Apollo team conquered those. The difficulty has been a lack of urgency — space funding and operating as usual. For example, Orion and its SLS booster have been under development since 2005, yet Orion has flown just a single test flight, in 2014. The Constellation program of the 2000s, never funded as promised, slipped, shrank and never came close to its lunar target date of 2019. The Obama administration canceled it in 2010. Dawdling by stretching out the return to 2028 or beyond as discussed in Congress would be a recipe for failure.

To get on track, we must first enlist our space station partners and commercial space firms in committing to a 2024 return to the moon. The fast-paced challenge will try all of them.

Second, we must advance the testing and flight schedule for Orion and SLS, launching a first crewed mission by late 2021 or early 2022. The 2024 deadline leaves almost no margin for further delays in Orion crewed flights. After the lunar return, we'll need to launch at least one crewed SLS per year.

Third, we must launch the first elements of the lunar Gateway into orbit around the moon by 2022. Commercial space firms can help build and deliver this small outpost in time for the landing deadline.

Fourth, NASA must follow up its July "Human Landing System" kickoff with a fast-paced industry lander development program, competing several designs to create the machine that will deliver Americans to the moon's surface.

Fifth, we must obtain advance information on polar landing sites, sending small, commercially developed landers to search for safe landing zones and prospect for ice.

Hitting these marks will enable NASA and its international partners to construct a lunar outpost near the moon's south pole by 2028. There we will plumb the scientific mysteries of the moon and prove the landers, spacesuits, mining gear, water and rocket fuel plants, and nuclear generators needed for travel to Mars and beyond.

Bold plans must be matched by necessary resources, a task that now falls squarely on the shoulders of Congress.

End the endless false starts

Since 1990, NASA has failed at two attempts to organize and sustain an American return to the moon. The 2024 deadline is ambitious, but speed is a galvanizing force. The tight timeline has energized the agency and will enlist public and international support. However, if Congress defaults to the cash-strapped pace of the past 15 years, by 2030 we will watch a competing space power land its explorers on the moon. Without a sense of urgency, we will surely lose our technological edge in space and on Earth.

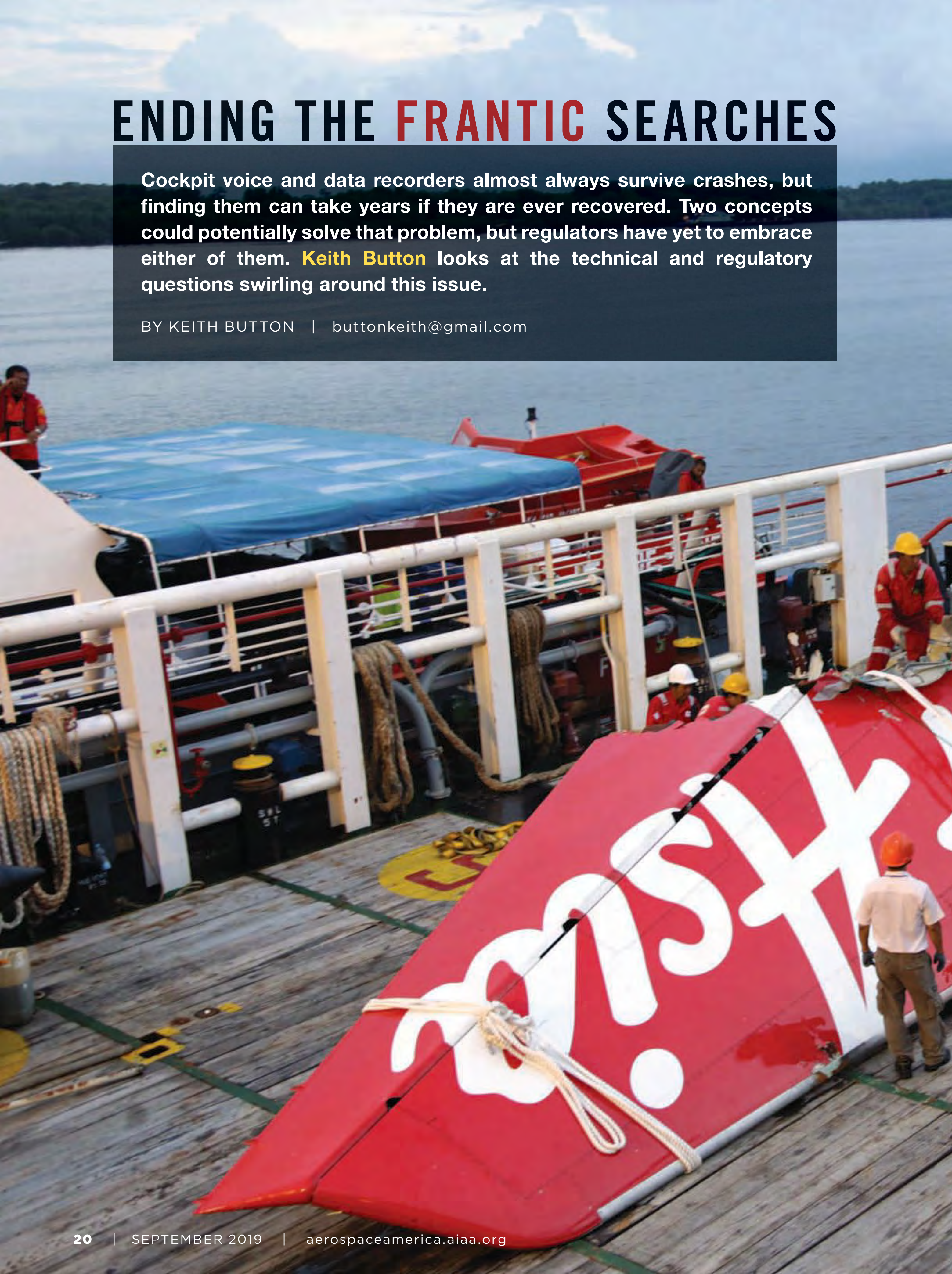
Reigniting the competitive spirit that served us so well during Apollo, we will return to the moon for technology, science and commerce. We will ensure that Earth-moon space will be open to liberty-loving peoples, their democratic legal structures and free markets. Leading a partnership of free, space-faring nations back to the moon is a vital step on an exciting American journey. Let's again make that "giant leap" we took first in 1969 — and keep on going. ★

Flight controllers practice for Artemis 1, Orion's uncrewed flight 64,000 kilometers beyond the moon and back to Earth, at Johnson Space Center in Houston.
NASA

ENDING THE FRANTIC SEARCHES

Cockpit voice and data recorders almost always survive crashes, but finding them can take years if they are ever recovered. Two concepts could potentially solve that problem, but regulators have yet to embrace either of them. Keith Button looks at the technical and regulatory questions swirling around this issue.

BY KEITH BUTTON | buttonkeith@gmail.com



Wreckage from AirAsia Flight 8501 is taken to port after searchers found it in the Java Sea. The airliner was flying from Surabaya, Indonesia, to Singapore when it crashed Dec. 28, 2014. Searchers found the flight data recorder on Jan. 12, 2015, and the cockpit voice recorder the next day.
AP Photo/Achmad Ibrahim

Authorities spent 1,046 days searching for the black boxes and wreckage of Malaysia Airlines Flight 370 in the Indian Ocean. At one point, tantalizing news broke that an Australian ship may have detected pings from an underwater beacon on either the cockpit voice recorder or the flight data recorder. The trouble was, the pings were faint, suggesting that the locator batteries were running low or that the searchers were still far away. At this writing, neither the flight data nor cockpit voice recorder has been found.

In this respect, MH370 is not unique. Records show numerous cases in which one or both of the recorders was never recovered. (See Page 25.)

On Jan. 1, 2021, the air transport industry will take what could turn out to be a momentous step toward ending these desperate and sometimes fruitless searches for black boxes. That's when a technical standard goes into effect calling for "timely recovery" of flight data and cockpit audio. The standard was approved in 2016 by the United Nations International Civil Aviation Organization, ICAO. Though the standard is not a requirement and it is aimed at freshly minted designs, some in the industry hope airlines will agree to it and retrofit their existing aircraft too. This would prevent some planes flying out of scope with such an important safety standard.

Whether the standard will have the desired impact remains unclear. A fierce competition is playing out between two basic concepts: ejectable black boxes versus technology for streaming cockpit voice and flight data to the ground via satellite. Meanwhile, another camp argues that the aircraft tracking requirements established after MH370 suffice.

Airbus favors the ejectable boxes, also known as automatic deployable flight recorders, and, in fact, has begun installing them on its newest jets. As for Boeing, the company says deployable boxes need more study partly due to the "risk of inadvertent deployment over populated areas." Boeing tested streaming technology on its 777 EcoDemonstrator in 2018 and says that this technology, too, has "unresolved technical and safety issues that must be addressed."

Missing regulations

The ICAO standard applies to new designs carrying at least 19 passengers and weighing 27,000 kilograms or more. If newly certified Airbus and Boeing passenger jets are about the size of today's, all will be covered by that weight threshold. Often a standard like this one would be reflected in regulations crafted subsequently by the European Union Aviation Safety Agen-

Investigators recover the flight data recorder of Atlas Air Flight 3591, a Boeing 767-300 cargo jet that crashed in marshland near Houston in February.
NTSB

▲ **This flight data** recorder was recovered from the crash site of West Air Sweden Flight 294, a Bombardier CRJ200 that went down in Sweden in 2016. Despite the heavy damage, data was was retrieved.

Swedish Accident Investigation Authority

cy, which certifies new Airbus designs, and the FAA, which certifies new Boeing designs. Those aircraft comprise 99% of the large passenger jet market, according to Teal Group of Virginia. FAA told me in a statement that it "does not plan to implement regulations on this issue," because it feels that existing regulations already meet or exceed the ICAO timely recovery standard. EASA says "quick retrieval" of flight recorders will be assured by a 2023 mandate requiring aircraft to be equipped with a "robust and automatic means" of determining the "end point" of a flight so that the precise crash location can be deduced.

Ultimately, it could be regulators from the Asia-Pacific region who take the lead on turning the standard into a requirement, given the oceanic nature of their routes and their frustrations over the MH370 disappearance, says Miguel Marin, ICAO's head of operations. He predicts that regulators there will require aircraft in their airspace to have new technologies onboard that meet the ICAO standard.

Of course, even if regulators do turn the standard into a requirement for new designs, that could still leave thousands of existing aircraft flying for years to come with the older technology. I contacted a sampling of U.S. airlines to find out if they plan to retrofit their fleets to meet the timely recovery standard. Delta Air Lines said, "We feel that we have the ability with current tools to meet the expectation" of the ICAO standard "without having to purchase new or unplanned technology." Southwest Airlines said it "does not have a position on the topic." United Airlines deferred to the Airlines for America, a lobbying group, which said, "there are already near real-time streaming flight data capabilities on newer aircraft and a growing percentage of the overall U.S. airline fleet." This is a reference to the maintenance data that airlines are starting to receive from aircraft in flight via services offered by the manufacturers. The group also noted that the Automatic Dependence Surveillance-Broadcast, or ADS-B, radios that airliners are starting to carry "provide the accuracy and safety benefits of real-time surveillance," the implication being that the location data in the ADS-B transmissions would narrow the search area and assure timely recovery.

Not everyone agrees, including the chair of the ICAO group that wrote the guidance for the timely recovery standard. "There are a lot of people thinking that because you find the wreckage under water, you will find the recorder automatically, 100%," says Philippe Plantin De Hugues, a senior safety investigator at BEA, the French aviation accident investigation agency. He has documented at least 15 over-water accidents in which either the cockpit voice recorder, the flight data recorder or both were never found. He noted that searchers needed two months to find the cockpit voice recorder for the Lion Air 737 MAX that crashed last October off Indonesia in only 30 meters of water. As for the maintenance data, he says it's insufficient for accident investigators.

Ejectable boxes

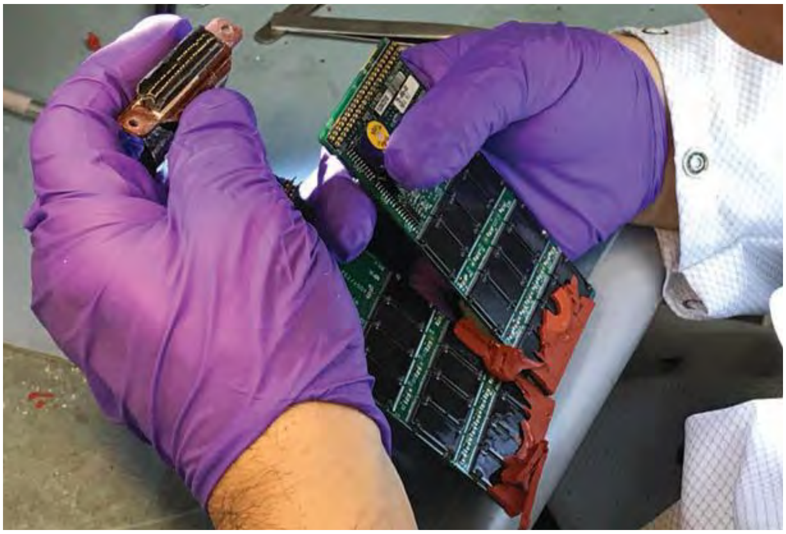
Avionics supplier L3Harris Technologies of Florida says the standard can be met by the combined cockpit voice and flight data recorder that it has begun selling. This Automatic Deployable Flight Recorder would spring from the tail of the plane on impact and, in a water crash, float instead of sinking with the wreckage or debris like conventional black boxes. The device is recessed into the surface of the fuselage to avoid aerodynamic complications. Conventional black boxes are sometimes carried in the tail as separate boxes for audio and data, while other versions combine the functions into one box, and then for redundancy identical versions are kept on an equipment rack in the front of the plane and in the tail.

Airbus has endorsed the ejectable concept, and the company is installing one on each A350 XWB, the new wide bodies that Airbus started delivering this year. The company pledges to install the boxes on all future Airbus planes too.

Streaming data

Another school of thought calls for avoiding the need to recover black boxes at all. The data would be streamed, and to keep satellite communications costs under control, this probably would be done by triggering the service in an emergency.

Curtiss-Wright Corp. of North Carolina and erstwhile rival Honeywell of New Jersey are jointly developing black boxes that would do this. Meanwhile, FLYHT Aerospace Solutions of Calgary, Alberta, which worked with Boeing on the streaming demonstration in 2018, is marketing a black box streaming service but has so far lined up only a handful of customers, including First Air, an Ontario-based airline, the only one that it named. These customers



▲ **Memory boards** from the cockpit voice recorder of Atlas Air Flight 3591, which crashed in February near Houston.
NTSB

have signed up for flight data streaming, not voice.

The cost of satellite bandwidth is a big challenge for these concepts.

In fact, Plantin De Hugues offers a tentative prediction. He says until the transmission prices come down, the near-term solution may be the ejectable black boxes. He offers a caveat: Installations of ejectable boxes can be expensive, which could make short bursts of data an attractive alternative.

Backers of streaming are upbeat about carving a near-term role.

FLYHT addresses the cost problem by giving its customers the option of triggering its black box service, called FLYHTStream, only in an emergency, says Derek Graham, FLYHT's chief technology officer.

Thomas Schmutz, the FLYHT CEO, predicts that satellite bandwidth eventually will become a commodity and, as with cellphone data plans, prices will come down. With lower prices, aircraft in the future will be connected via satellite links to the ground continuously, Schmutz says, and aircraft operators will be able to view all the aircraft data in real time, on the ground. Eventually, customers could view virtual projections of aircraft in flight that would allow on-the-ground safety monitoring and diagnosis of technical problems before they lead to crashes.

Streaming costs would add up quickly today if it were done continuously, given the potential volume of data produced by each airplane. Today's passenger plane flight data recorders record at least 88 flight data parameters — the minimum required by the FAA — such as the position of control surfaces on the wings and engine data, for example. Data recorders for newer passenger planes like the Airbus A350 and Boeing 787 can record thousands of parameters, so the bandwidth required to transmit all the data, and the associated costs, could be substantial.

Hardware costs might or might not prove to be a big obstacle. Rigging an airliner for streaming would cost $70,000 per plane, according to the 2015 "Air Safety" report by the U.S. Government Accountability Office. That's about 0.03% of the cost of a Boeing 787 or Airbus A350 XWB. Of course, even a small increase adds up to a large number across thousands of aircraft.

Difficult choice

Another question is what satellite frequency to communicate in. Because of their wavelength, L-band satellites can establish links with aircraft even through clouds and precipitation. The L band already carries airplane tracking data via Iridium satellites and the Aireon aircraft surveillance service, for example. But there isn't enough L-band spectrum available to handle the volume of data that black box streaming would demand, says Lisa Kuo, director of connectivity technical sales at Panasonic Avionics Corp. of California, which supplies passenger communication and entertainment services to airlines.

The higher-frequency Ku- and Ka-band options, which carry internet and streaming services for airplane passengers, are less reliable in wet weather. That said, Ku and Ka bands may be a more likely option for black box data streaming because the cost to transmit data via L-band satellites is more than 10 times that of Ku and Ka bands, Kuo says.

In fact, this might be one reason that some expect authorities to always want black boxes in some form on a plane, even if it is equipped for streaming. Today, each box weighs about 3 kilograms, so keeping them does not pose an equipment challenge. Regulatory authorities will always want recorders aboard in case the satellite link fails or another unforeseen problem arises, says Chris Thomson, the United Kingdom-based vice president for business development at Curtiss-Wright.

Securing the audio and data stream

Those who favor streaming know that the transmissions must be encrypted to protect them from hackers. ICAO has urged regulators to make sure that satellite-streamed data is not intercepted or altered as it moves from the plane to the ground.

Honeywell and Curtiss-Wright are still ironing out the level of encryption that will be necessary for the downlinks from their data-streaming flight data and cockpit voice recorders, says Curtiss-Wright's Thomson. Whether the data encryption should be equivalent to that of military communications in a war scenario, or to that of an online credit-card purchase, or some other level, has yet to be decided. At issue is making sure the data is secure while balancing the costs and benefits for the chosen level of encryption.

Those who watch developments in this area see promise in the concept. If the plane crashed, "now you have the flexibility of having real-time data,"

In one sense, MH370 was not unique

Fifteen times over the decades a plane has crashed into a body of water and one or more of the black boxes were never recovered.

CRASH	DATE	AIRCRAFT	LOCATION	FLIGHT DATA AND COCKPIT VOICE RECORDER
Malaysia Airlines Flight 370 Disappeared and crashed somewhere in Indian Ocean, killing 239.	March 2014	Boeing 777-200ER	Indian Ocean	Neither recovered
Asiana Airlines Flight 991 This cargo plane crashed off South Korea after a fire broke out on the main deck. Both pilots died.	July 2011	Boeing 747-48F	Off Jeju Island, South Korea	Neither recovered
Siberia Airlines Flight 1812 Destroyed by a Ukrainian missile over the Black Sea. All 78 aboard were killed.	October 2001	Tupolev TU-154M	Black Sea near Crimea	Neither recovered
Faucett Airlines [flight number unknown] Crashed off Newfoundland after the crew reported low fuel. The aircraft and the 16 aboard were never found.	September 1990	Boeing 727-247	Atlantic Ocean near Newfound-land	Neither recovered
Iran Air Flight 655 Shot down by crew of USS Vincennes after misidentifying the airliner as an attacking warplane. All 290 aboard were killed.	July 1988	Airbus A300B2-203	Persian Gulf	Neither recovered
Korean Air Flight 858 Exploded off the coast of Myanmar, killing all 115 aboard. A North Korea defector admitted to planting a bomb.	November 1987	Boeing 707-3B5C	Indian Ocean	Neither recovered
South African Airways Flight 295 All 159 people aboard died when an onboard fire caused the aircraft to break apart and fall into the Indian Ocean.	November 1987	Boeing 747-244B	Indian Ocean off Mauritius	Flight data recorder recovered; cockpit voice recorder was not
Varig Flight 967 Disappeared en route to Brazil 30 minutes after takeoff from Tokyo.	January 1979	Boeing 707-323C	Pacific Ocean	Neither recovered
SATA Flight 730 Crashed off Portugal after the crew lost sight of the runway at Funchal Airport on Madeira Island. Thirty-six of the 57 aboard were killed.	December 1977	Sud Aviation SE-210 Caravelle 10R	Atlantic Ocean	Neither recovered, but aircraft was found in 2011
Transmeridian Air Cargo 3751 Crashed off Hong Kong due to an engine fire. All four crew members died.	September 1977	Canadair CL44	Pacific Ocean	Neither recovered
TWA Flight 841 An explosive detonated in the cargo compartment, and the plane crashed off Greece, killing all 88 aboard.	September 1974	Boeing 707-331B	Ionian Sea	Neither recovered
Pan Am Flight 816 A possible instrument malfunction caused the plane to dive into the Pacific Ocean. One of the 79 aboard survived.	July 1973	Boeing 707-321B	Pacific Ocean off Papeete, Tahiti	Neither recovered
China Airlines [flight number unknown] Crashed off Taiwan after a bomb exploded aboard, breaking apart the aircraft and killing all aboard.	November 1971	Sud Aviation SE-210 Caravelle III	Pacific Ocean off Penghu Island	Neither recovered
ALM 980 Ditched near the Virgin Islands after running out of fuel. Of the 63 aboard, 40 survived.	May 1970	McDonnell Douglas DC-9-33CF	Caribbean Sea	Neither recovered
United Airlines Flight 389 Crashed on descent into Chicago's O'Hare International Airport. All 30 aboard were killed.	August 1965	Boeing 727-22	Lake Michigan	Flight data recorder never recovered; not equipped with cockpit voice recorder

Credit: Philippe Plantin De Hugues of BEA, the French aviation accident investigation agency

ICAO

International Standards and Recommended Practices

Annex 6 to the Convention on International Civil Aviation

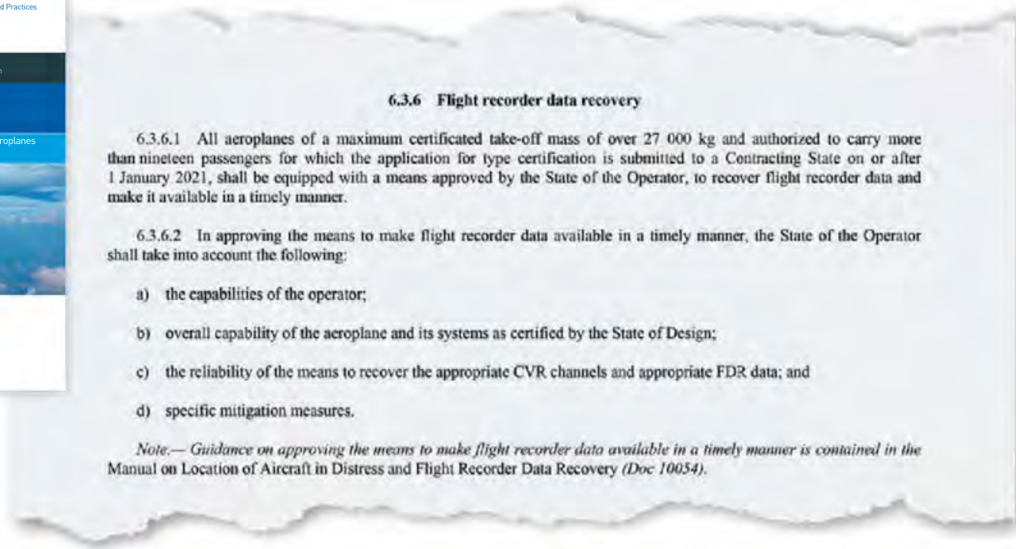
Operation of Aircraft

Part I — International Commercial Air Transport — Aeroplanes
Eleventh Edition, July 2018

This edition supersedes, on 8 November 2018, all previous editions of Part I of Annex 6.

For information regarding the applicability of the Standards and Recommended Practices, see Foreword.

INTERNATIONAL CIVIL AVIATION ORGANIZATION



6.3.6 Flight recorder data recovery

6.3.6.1 All aeroplanes of a maximum certificated take-off mass of over 27 000 kg and authorized to carry more than nineteen passengers for which the application for type certification is submitted to a Contracting State on or after 1 January 2021, shall be equipped with a means approved by the State of the Operator, to recover flight recorder data and make it available in a timely manner.

6.3.6.2 In approving the means to make flight recorder data available in a timely manner, the State of the Operator shall take into account the following:

a) the capabilities of the operator;

b) overall capability of the aeroplane and its systems as certified by the State of Design;

c) the reliability of the means to recover the appropriate CVR channels and appropriate FDR data; and

d) specific mitigation measures.

Note.— Guidance on approving the means to make flight recorder data available in a timely manner is contained in the Manual on Location of Aircraft in Distress and Flight Recorder Data Recovery *(Doc 10054).*

▲ **The ICAO standard** related to flight data recovery was adopted in reaction to the disappearance of Malaysia Airlines Flight 370.
ICAO

says Daniel Adjekum, an assistant aviation professor at the University of North Dakota and former aviation accident investigator in Ghana. Investigators could quickly decide which aircraft components or flight crew actions to focus on.

They could see from the streamed data where the aircraft departed from its assigned altitude and its rate of descent, for example, along with essential information that might be gleaned from the pilot's control inputs and communications, or from engine data.

Combining with other standards

In addition to timely recovery of flight data, ICAO issued two other standards in 2016 aimed at preventing another lost plane scenario like MH370. One standard requires planes to transmit their location at least every 15 minutes; the other requires planes in distress to transmit their location once a minute via a system that cannot be shut off by someone on the plane. The 15-minute standard is met by the ADS-B radios that most airliners carry and will have to carry in the U.S. starting in January. ADS-B does not fully meet the once-a-minute standard, because the ADS-B transponder could be shut off by someone.

Despite their limits, ADS-B transmissions figured into Canada's fast response to the crash of the Ethiopian Airlines 737 MAX jet in March after takeoff from Addis Ababa. The transmissions were picked up by Iridium satellites and routed to NAVCANADA, the Canadian air traffic control company that is part of the Aireon surveillance venture. Canadian authorities realized that the flight path resembled that of the Lion Air 737 MAX that crashed a few months earlier, and so they grounded all MAX planes in their airspace as a precautionary measure.

With streaming, investigators would have far more data to go on right away plus the cockpit conversation. "We can certainly imagine a world where [the Boeing 737 MAX crash data] would have been more available much more quickly for whatever the corrective action might have been, to have started earlier rather than later," Thomson says. "The more quickly and the more data you can pull off the aircraft, the better chance you have of converting that data into timely information upon which you can take some sort of investigative or corrective action."

Implications for maintenance, repair and overhaul (MRO)

The 2021 deadlines are spurring demand by airlines not just for streaming black box data, but data that could improve their flight operations. For example, FLYHT, the streaming company, offers thousands of parameters for airplanes in flight for real-time monitoring of fuel consumption, crew performance, weather conditions and airplane health. Customers — the airplane operators — can make in-flight adjustments based on the data to save on fuel costs or diagnose maintenance problems in flight before they lead to costly repair problems, or spot airplane health problems that could interfere with on-time performance goals. If they are already setting up a satellite link for transmitting the black box data, then it might make business sense to carry maintenance and operations data over the link also, or vice versa.

As new technologies are wrapped into aircraft, one thing innovators plan to stay focused on is their culture of safety.

"Aerospace is a very conservative industry, with a lot of room for innovation, but that innovation is always tempered," Thomson says. "We operate in three dimensions. You get into a bit of difficulty in your car, and you pull over. You can't really pull over at 38,000 feet, so there's always a preponderance of safety." ★

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AIAA
SHAPING THE FUTURE OF AEROSPACE

SMALL SATELLITES, BIG WEAK

Constellations of microsatellites are starting to provide imagery, communications bandwidth and weather data to customers quickly and affordably. So what could possibly go wrong? Plenty, unless this sector gets its cybersecurity house in order. The good news, reports Debra Werner, is that some are starting to do just that.

BY DEBRA WERNER | werner.debra@gmail.com

Earlier this year, a U.S. Air Force officer visited a microsatellite operator to warn of the danger of criminals or nation-state hackers breaking into the company's network to disable satellites or steal intellectual property such as satellite designs or software.

"It scared the hell out of me," says the CEO, who asked me not to publish the company's name for fear of making it more of a cyber target.

The visit from the Air Force officer was a sign of changing times. For decades, government agencies or multinational corporations controlled the vast majority of satellites, and many of those satellites were as large as school buses. Data was received and commands were sent through private networks backed by sophisticated security apparatuses.

Now, startup companies are hooking up simple microsatellites (weighing 10 to 100 kilograms) to the internet for affordability and the convenience of customers, including the Air Force in some cases. Imagery, weather data and communications bandwidth are delivered this way. Commands to the satellites travel through the internet to satellite ground stations and up to space.

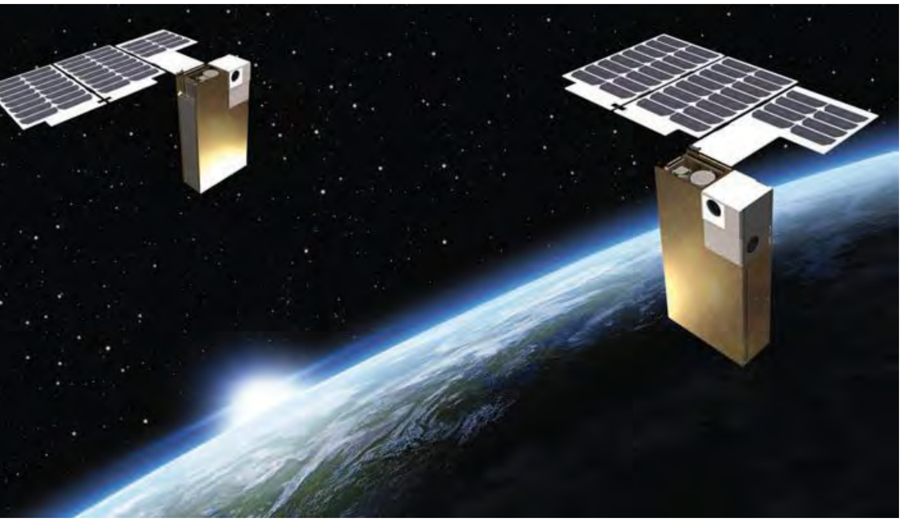
Cybersecurity experts are sounding the alarm about the vulnerability of this new way of doing business.

"Microsatellites are completely driven by software and completely networked. That's where the vulnerability comes in," says Sam Adhikari, operations and research vice president for Sysoft Corp., a big-data analytics company in New Jersey, and chair of AIAA's Aerospace Cybersecurity Working Group.

Cyber experts don't necessarily think companies must disconnect their satellites entirely from the internet. In our example, the CEO quickly hired outside experts to identify and shore up vulnerabilities in the firm's private computer network and its connections with the internet. They warned that an employee on an overseas trip could unwittingly create a conduit to the company's satellite constellation and blueprints by firing up a laptop on public Wi-Fi. So, employees are no longer allowed to bring their work laptops on many such trips. Instead, they travel with blank laptops containing no information about the company or its satellite constellation. When employees return from overseas, the laptops they carried are wiped clean to prevent any malware they may have picked up from spreading to corporate networks.

Adapting cybertactics to space

On Earth, cybersecurity professionals set up servers called honeypots that are identical to those of the internet or a company's intranet, except that they are laced with spyware. The honeypot strategy takes



▲ **Gunsmoke-L microsatellites** are "information collection" spacecraft in development for the U.S. Army. They are representative of the new class of satellites whose cyber connections could be attractive to hackers.
Dynetics

advantage of the fact that cyberattacks don't typically come out of the blue. Hackers must observe networks closely for months or even years, poking at firewalls and investigating network security before attempting to break in. By tracking the behavior of a hacker at a honeypot, cybersecurity experts can create the equivalent of a fingerprint or signature for the hacker, learn his tactics and develop defenses.

Cybersecurity companies have adapted this concept to microsatellites. Satellite honeypots look like every other satellite in a constellation but instead of relaying communications or gathering imagery, their job is simply to record hacker behavior. How are hackers approaching the network? Are they identifying vulnerabilities? What do they do once they gain access?

With that information, satellite operators can safeguard other satellites in the constellation.

"I can't tell you very much" about this defense mechanism, Adhikari says, "but I can tell you the decoys are out there."

Overall, the name of the game is predictive analytics. Patterns of behavior of would-be hackers are continuously compared to the behavior of those who are authorized to communicate with individual satellites, whose day-to-day operations are logged. Based on subtle differences, the software can predict the presence of a hacker.

Fighting back

The U.S. once hesitated to publicly attribute hacking, but that is no longer the case. In July, FBI Director Christopher Wray told lawmakers that China is responsible for almost all of the 1,000 cases of intellectual property theft that the FBI is investigating. China's Foreign Ministry spokeswoman Hua Chunying dismissed the allegation of cybertheft as "baseless."

Some of the U.S. allegations center on space technology. "China has a well-understood and effective national strategy to become the global, dominant space power," a key part of which is to "penetrate and dominate elements of the global space industrial base while developing their own strong national space industrial base," according to the report "State of the Space Industrial Base: Threats, Challenges and Actions," released in May by the Air Force Research Lab and the Pentagon's Defense Innovation Unit.

No matter the origin, the intrusions are increasingly sophisticated.

"We're not talking about your average, run-of-the-mill hacker who's trying to steal some credit card information," says Frank Backes, who leads federal space programs at Kratos Defense and Security Solutions in San Diego, whose products include network operations centers and satellite communications networks. "We're talking about a state-sponsor kind of threat, where the state is interested in the design of your satellite, your satellite communications infrastructure and where vulnerabilities might exist."

To strengthen U.S. cybersecurity, the White House National Security Council and the interagency Space Science and Technology Partnership Forum in April announced formation of the Space Information Sharing and Analysis Center, or Space ISAC, in Colorado Springs, Colorado. This nonprofit organization will help companies flying satellites work with government agencies to analyze satellites and ground networks looking for physical and cyber threats, share information and respond if attacked.

Kratos, the Department of Homeland Security's National Cybersecurity Center, the Mitre Corp. and Booz Allen Hamilton, the management and consulting firm headquartered in McLean, Virginia, were first to sign on as members of the Space ISAC. Additional international organizations, companies and national laboratories are in the process of signing up, including satellite builders, space launch companies and satellite operators.

Space ISAC dues-paying members commit to working cooperatively to prepare for and respond to threats, share information on vulnerabilities, incidents and threats with other members, and spread the word about the organization.

The Space ISAC was created, in part, to respond to a presidential Space Policy Directive and to the U.S. National Cyber Strategy. The Trump administration's Space Policy Directive 3 issued in June 2018 says the United States must promote "space safety standards and best practices across the international community." While it doesn't mention cybersecurity specifically, it's implied, says Scott Kordella, Mitre executive director for space systems.

The National Cyber Strategy, released in September 2018, highlights "evolving cyber threats" and says the administration will "work with industry and international partners to strengthen the cyber resilience of existing and future space systems."

Bold step

To sharpen cybersecurity, the Federal Communications Commission is considering making satellite operators encrypt communications between spacecraft and ground stations. Most satellite operators already encrypt telemetry, tracking and command messages to prevent anyone from hijacking a spacecraft or intercepting communications. But without a federal requirement, some microsatellite operators choose not to encrypt because it's an added expense and can slow communications traffic.

The FCC's proposed rules published in February would require operators of satellites with onboard propulsion to encrypt telemetry, tracking and command information. The comment period closed in April, but no final rules had been issued as of Aug. 1.

Encryption of satellite communications is critical because ground stations are "the soft underbelly" of satellite networks, says Marc Jamison, a retired U.S. Air Force colonel who heads Cyber Checkmate Consultants, a firm based in San Antonio that advises companies on cybersecurity. "If someone is able to implant themselves in your ground stations, they can take control of your satellites."

How bad can it get?

Space experts say it's unlikely a hacker could hijack a satellite and crash it into another. The hacker would need extensive knowledge of orbital mechanics plus a feedback loop to gauge the progress of such an attack. Still, no one wants to risk a hacker disabling a satellite, stealing Earth imagery or disrupting communications.

"Maintaining positive control over your spacecraft is very important," says Steve Nixon, president of the SmallSat Alliance, a nonprofit industry association that advocates for expanding the roles of small satellites in government programs.

Cybersecurity experts are particularly concerned about cybersecurity at some of the startups with fewer than 100 employees that are building microsatellites. They generally don't employ chief security officers or hire anyone trained in securing networks.

"Big companies building the megaconstellations aren't the only ones we need to help," says Kordella of Mitre. "How will the smaller companies, who will be operating satellites in low Earth orbit along with them, protect themselves and therefore their neighbors as they fly?"

Protecting the crown jewels

Like all satellite builders, firms developing microsatellites should consider cybersecurity long before their satellites reach orbit, says Adhikari of Sysoft.

Engineering documents for spacecraft and ground networks should be stored in computers with no

▼ **A team at the U.S. Air Force's Arnold Engineering and Development Complex** in Tennessee prepare a microsatellite for a test.
U.S. Air Force/Jacqueline Cowan

links to the internet. Engineers should scrutinize the commercial hardware and software they install in satellites and ground stations.

Companies also need to routinely monitor communications traffic so they can detect anomalies.

Even if they take all those precautions, foolproof security is impossible. "Focus on being adaptive, prepared and resilient so you can evolve as threats and vulnerabilities evolve and continue functioning when an issue does arise," says Michael Johnston, who leads Booz Allen's space and nuclear business.

Unlike large government contractors that purchase satellite parts exclusively from carefully vetted suppliers, microsatellite builders often buy computer chips and other parts off the shelf. Those parts could have built-in backdoors offering hackers a way to bypass traditional mechanisms for authenticating satellite commands. You don't know unless you do a vulnerability analysis, Jamison says.

Small-satellite developers also tend to pick up software from GitHub or other commercial vendors. "If you are talking about putting something on orbit in a year, you can't necessarily do a bunch of scrubbing on what that software is and what it does," says Ryan Speelman, principal director of the cybersecurity subdivision at the federally funded Aerospace Corp. in Los Angeles, which conducts research and development for the Air Force and National Reconnaissance Office, the agency that buys and operates U.S. spy satellites.

To remedy the problem, the Aerospace Corp. wants to make it easier for satellite operators to detect intrusions. Microsatellite builders could add the intrusion-detection software to their flight software. Larger spacecraft could carry an intrusion-detection computer that would be equipped with artificial intelligence to assess threats.

Both versions would notify satellite operators when anyone outside their trusted network penetrates a satellite's defenses. Aerospace Corp. also wants the software or hardware to reveal the source of cyberattacks. With that information, satellite operators could quickly fend them off, Speelman says.

He thinks quick attribution of cyberattacks could help discourage them. Hackers generally believe they won't get caught. "If you can rapidly attribute the attack, you make it a much less attractive mechanism for an adversary," he says.

The first prototype of the Aerospace Corp. intrusion detection system could fly in 2020. Until then, microsatellite operators like their counterparts flying billion-dollar spacecraft will turn to cybersecurity experts in government and industry for advice on the best way to fend off attacks. ★

Staff reporter Cat Hofacker contributed to this feature.

A prototype microsatellite built by ICEYE in Finland.
ICEYE

GENERATION

For the U.S. and countries that buy its warplanes, the upgrade to fifth-generation fighters won't be like flipping a switch. In fact, Boeing and Lockheed Martin each have proposals to soup up the designs of their decades-old fourth-generation fighters, the F-15 and F-16. Jan Tegler looks at the arguments for and against the F-15EX and F-21.

BY JAN TEGLER | wingsorb@aol.com

AL CONFLICT

Air power strategists in the Pentagon and Air Force have long billed today's F-22 and F-35 variants as the aircraft that will keep the U.S. ahead of adversaries through at least 2060. These fifth-generation fighters are stealthy and loaded with sensors that create a complete picture of the airspace that can be shared with other aircraft, ground vehicles, ships and command centers. They are the Swiss Army knives of fighters and are far more lethal than the fourth-generation F-15s and F-16s flown by the U.S. Air Force.

Over the past year, however, manufacturers have proposed two fighter concepts that challenge the notion that the U.S. Air Force and equivalent services abroad should jump straight from today's fourth-generation jets to the fifth generation.

One proposal, revealed by Boeing in July 2018, calls for updating the F-15 design that Boeing inherited with its purchase of McDonnell Douglas in 1997. The new version would be called the F-15X and would come in a two-seat F-15EX version and maybe someday also a single-seat CX model. Pitched as a cost-effective, low-risk replacement for today's F-15C, the F-15EX would combine the F-15's proven airframe with a selection of sensors, avionics, self-protection systems (electronic jamming) and offensive weapons similar to those on fifth-generation fighters.

The way budget deliberations are unfolding in the U.S., it looks like Congress could come close to meeting the Air Force's request for \$1.1 billion in fiscal 2020 to buy the first eight of 80 F-15EXs to be purchased over the next five years for \$7.8 billion. The House Appropriations Committee would provide

▲ **A U.S. Air Force F-35A**, above, and an illustration of Boeing's proposed F-15EX, left.

U.S. Air Force and Boeing

$986 million for eight F-15EX planes to replace the F-15C and its F-15D trainer models, according to the bill the committee passed in June. The authorization bills in the House and Senate also call for eight aircraft but would trim the cost a bit to $941 million in the House version and $948 million in the Senate. Boeing also offered the Air Force the single-seat version, but the service has not announced plans to buy this.

Meanwhile, at a February trade show in India, Lockheed Martin showed off a small-scale model of a derivative of the F-16 to be called the F-21. Unlike the F-15EX, the F-21 would not be intended for the U.S. Air Force. Lockheed Martin hopes to sell the F-21s to the Indian Air Force through the U.S. foreign military sales process. The F-21 would follow a similar formula of doing as much as possible with a nonstealthy airframe. The planes would be enhanced versions of the Block-70 F-16s that Lockheed Martin produces in Greenville, South Carolina, for export. Like the F-15EX, the F-21 would incorporate fifth-generation technology, including an active electronically scanned radar and what Lockheed Martin calls an "India-unique" electronic warfare suite for self-protection along with improved avionics, data links and the ability to fire a range of air-to-air and air-to-ground weapons.

I spoke to analysts, defense officials and corporate executives, some of whom would not be named so they could speak freely about the merits of the F-15EX and F-21 proposals.

Selling the F-15EX

The Air Force wants to wrap the F-35A into the force to achieve a 50-50 ratio of fourth-generation fighters and fifth-generation F-22s and F-35As. Planners face a conundrum, though, with the F-15Cs designed exclusively to shoot down other aircraft. Their internal longerons are showing signs of fatigue, and the Air Force calculates that if nothing is done the planes will need to be retired between 2023 and 2028. The F-15EXs could replace them.

Air Force leaders initially opposed buying any additional fourth-generation fighters, including the F-15EX, viewing it as distraction from procuring F-35As. Here's then-Air Force Secretary Heather Wilson speaking to Defense News last September: "... getting to 50-50 means not buying new fourth-gen aircraft, it means continuing to increase the fifth generation."

Wilson's view did not prevail in the 2020 budget request; after leaving the Air Force in May, she became president of the University of Texas at El Paso.

Retired Air Force Lt. Gen. David Deptula reported in Forbes in March that the Office of the Secretary of Defense "drove" a decision to include F-15EXs in the request released that month.

The Air Force's hesitancy to embrace the F-15EX proposal might be understandable. The service selected McDonnell Douglas' design for the F-15 in 1967. Even with some fifth-generation technology, these planes will never be as capable as the 1980s-designed F-22 or 1990s-designed F-35A, some defense analysts and U.S. senators argue. A combination of stealth and sensor fusion enables the F-22s and F-35As to simultaneously perform multiple missions amid defenses that would rapidly destroy or cripple the F-15EX.

Also in this view, employing a mixed force of F-35As, F-22s and F-15EXs would require greater numbers of expensive support aircraft to ensure that fourth-generation fighters could survive and be effective against sophisticated adversaries. That support would include electronic warfare aircraft and airplanes capable of suppressing surface-to-air missile systems.

F-35A backers also worry that the U.S. may have passed the apogee of the Trump increase in defense-spending and that even a small buy of F-15EXs would mean fewer F-35As. That outcome would dent the capability of an already fighter- and pilot-poor Air Force, even with the F-35A's development woes and delays.

So far, the fear has not born out that F-15EXs might be procured instead of some F-35As. The 2020 budget request calls for a buy of 48 F-35As per year, the same rate requested in the 2019 defense budget. This comports with Lockheed Martin CEO Marilyn Hewson's prediction from January that if Boeing-built F-15EXs are purchased, it "won't be at the expense of F-35 quantities," adding that she was "hearing that directly from leadership in the Pentagon."

Rather than taking funds from the F-35A, the F-15EX acquisition funds would be drawn from money that would have been used to keep the F-15C flying. F-15EX supporters note that keeping Boeing's F-15 line up and running also would preserve diversity in American fighter manufacturing.

Perhaps, in talking up the F-15EX, these supporters are pushing back against those who don't like the plane's lack of stealth. They cite a list of pluses about the F-15EX, even if they don't necessarily mean that the Air Force should buy them instead of F-35As. When it comes to dollars, they predict that the F-15EX will retain an edge in unit cost over the F-35A. This will be true, they say, despite an agreement announced in June between the F-35 Joint Program Office and Lockheed Martin that would seek to bring the unit cost of the F-35A in the next lots to under $80 million. That's about the predicted unit cost of an F-15EX, but the F-15EX supporters do not believe this will be achieved.

That still leaves the question of cost per flight hour. F-15EX advocates say the hourly cost will be almost half that of the F-35A. Pentagon officials seem to agree. In early May, Vice Adm. Matt Winter, director of the F-35 Joint Program Office, told a House subcommittee that the current flight-hour cost for the plane is $44,000. During the same hearing, Robert Daigle, director of the Pentagon's Cost Assessment and Program Evaluation Office, said his office projects a cost of $29,000 per flight hour for the F-15EX.

Another plus would be that the Air Force would at least temporarily avoid any interruptions in readiness because integrating F-15EXs into the force would be relatively straightforward. In mid-March, Maj. Gen. David Krumm, Air Force director of strategic plans, told Air Force Magazine that there is "80 to 90 percent commonality between the F-15C and the F-15EX" adding that the service expected it could transition units from F-15C to F-15EX in "less than six months." Krumm said transitioning to an all-new airplane could take between 18 months and three years for active-duty or Air National Guard units. "If you average that out, Active and Guard, each time we do that we save about two years of readiness," he said. F-15EX backers add that Air Force bases will not bear the expense of F-35A-specific construction of hangars and support equipment and that the cost of retraining pilots to fly the F-15EX will be negligible. The F-15EX can be plugged directly into existing F-15C squadrons.

The F-15EX would carry a larger payload of air-to-air missiles than the F-15C as well as smart bombs and missiles that can strike enemy air defense systems. It could also be flown on homeland defense missions with the capability to carry future air-launched hypersonic missiles to defend against Chinese or Russian hypersonic cruise missiles. The F-35A will likely be flown for this purpose as well but will have to carry the large weapons externally, negating its stealth.

The case for the F-21

Lockheed Martin's immediate goal with the F-21 is to position itself for an international fighter competition that India plans to start shortly. At stake would be the right to supply 114 fighters to India at a reported cost of $15 billion to $20 billion. India's Ministry of Defense specifies that roughly 97 of the 114 jets would be manufactured in India.

Opportunities to win Indian fighter business do not come often. The last foreign-made fighter to join the Indian Air Force is the Sukhoi Su-30, which India began flying in 1997. A formal request for proposals for the new acquisition reportedly could be issued this year or in 2020, with deliveries starting in the mid-2020s.

In the U.S., Lockheed Martin's statements about the program have provided tantalizing

Meet the generations

The U.S. and its allies may need stepping stones to a future of stealthy fighters. Here's the possible mix:

4TH GENERATION

F-15C
Manufacturer: Boeing
Maximum speed: Mach 2.5
Engines: Two P&W F100 or two GE F110 turbofan engines
Notes: Retirement looms between 2023 and 2028

F-15EX
Manufacturer: Boeing
Maximum speed: Mach 2.5
Engines: Two P&W F-100-PW-229 or GE F110-GE-129 – decision to come from U.S. Air Force
Notes: Proposed replacement for F-15C

F-16
Manufacturer: Lockheed Martin
Maximum speed: Mach 2+
Engine: One General Electric F110-GE-129 (Block 70) or one Pratt & Whitney F100-PW-229 (Block 72)
Notes: A hot export plane and foundation of proposed F-21 for India

5TH GENERATION

F-21
Manufacturer: Lockheed Martin
Maximum speed: Mach 1.8
Engine: One General Electric F-110-GE-129
Notes: Lockheed Martin wants India to buy these proposed jets

F-22
Manufacturer: Lockheed Martin
Maximum speed: Mach 2+
Engines: Two Pratt & Whitney F119-PW-100 turbofan engines
Notes: First flew in 1997, but first combat mission was in 2014

F-35A
Manufacturer: Lockheed Martin
Maximum speed: Mach 1.6
Engine: One Pratt & Whitney F135
Notes: Pentagon's largest acquisition program; total costs predicted to be $406 billion

▲ **An F-15C gets ready** to refuel with a KC-135 during a training exercise out of Kadena Air Base, Japan.
U.S. Air Force

fodder for speculation about the company's long-term plans. On its website, the company says that it will partner with New Delhi-based Tata Advanced Systems to accelerate "India-U.S. cooperation on advanced technologies." The reference to "advanced technologies" led to speculation that Lockheed Martin might view collaboration on the F-21s as a precursor to someday exporting F-35As to India. What does Lockheed Martin say about this theory? Any future sales of F-35As would be "a government-to-government issue," says Vivek Lall, the company's vice president for strategy and business development. If India does decide to pursue a fifth-generation fighter, the F-35A might be the only option. In 2007, India agreed to participate in the development of Russia's fifth-generation Sukhoi Su-57 fighter but pulled out of the program last year.

Lockheed Martin likes to emphasize that someone who buys an F-21 will get some technology similar to what's on the F-22 and F-35A. For example, the F-21's APG-83 radar "will have 85 percent hardware and software commonality" with the F-35A and F-22 radars, says Lall, and the planes "will share a common supply chain on a variety of components." Further sweetening its bid, Lockheed Martin announced an agreement with Tata last year to produce F-16 wings in India, adding that it expects to export F-16 wings from India for all future F-16 customers. Lall says Tata and Lockheed Martin are working on the first prototype F-16 wing now and expect to finish by next year. Tata could potentially produce "other supply-chain-side components" for the F-16, Lall notes. "That would all be part of that ecosystem that is part of our offer to India."

Such a move would be a boon to Indian Prime Minister Narenda Modi's "Make in India" initiative to improve the nation's military industrial base and create jobs. Defense analysts tell me the F-21 stands a good chance of winning the Indian order, with odds perhaps as high as 60 percent in its favor. They see Lockheed Martin's decision to partner with Tata as positive, noting that the two companies already partner in production of Lockheed's C-130J cargo airplane and that since 2009, Tata has been a reliable partner with Sikorsky, manufacturing cabins for its S-92 helicopter. Lall says Lockheed Martin's "decade-old deep partnership" with Tata has "built a lot of trust" and that with the outreach the company is doing with small and medium-size suppliers and startups in the Indian aerospace sector, "we think we can execute flawlessly in a timely manner should we be chosen for this contract."

In terms of capability, Lockheed Martin is keen to stress that the F-21 is a new offering rather than a rebranding of the Block-70 F-16s that it bid in India's earlier attempt at the procurement. "The F-21 is a unique configuration exclusively for the government of India with aspects that are unique to Indian requirements," Lall says. He adds that F-21s will first be built in the U.S. "with a phased transition to production in India."

Some analysts have contended that the company put a new name on the F-16 aircraft that it had previously proposed. The F-21 designation also could be an effort to distance the airplane from the memory of an earlier attempt to procure Western fighters that was started in 2007. This resulted in the selection of Dassault's Rafale in 2012. Seven years after this Medium Multi-Role Combat Aircraft selection, no Rafales have been delivered to the Indian Air Force as contract negotiations stalled over cost, technology transfer and allegations of corruption by the Modi government. Indian media reports indicate that four of the 36 Rafales on order may arrive next April or May.

The F-21 designation might also be meant to avoid conjuring thoughts of the F-16s that archrival Pakistan flies. That last concern was apparently born out in February after a suicide bomber attacked a bus carrying Indian paramilitary troopers, killing at least 40, according to press reports. India responded with an airstrike against what it described as a terrorist training camp inside Pakistan. In the ensuing skirmish, Pakistan shot down at least one Indian MiG-21 and captured a pilot who was released in March. India claimed to have shot down a Pakistani F-16, although Pakistan denied this.

The F-21 will be in competition with six other fighters: the Boeing F/A-18 Super Hornet, Dassault Rafale, Eurofighter Typhoon, Saab Gripen, Sukhoi Su-35 and MiG-35. All are fourth-generation jets that have been enhanced with varying levels of fifth-generation technology. Lockheed Martin could have an edge in that the F-21 is the only entrant with a connection to the F-35A. ★

Staff reporter Cat Hofacker contributed to this report.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Two big aerospace ideas

Humanity can't advance without big ideas, but big ideas can't become reality without sound economic underpinnings and a bit of courage. Dennis M. Bushnell explains.

BY DENNIS M. BUSHNELL

▲ **Passenger air** vehicles such as this one from Boeing's Aurora Flight Sciences company in Virginia could replace personal automobiles.
Boeing

One definition of a big idea is a concept or approach that upends conventional beliefs and behaviors and perhaps disrupts markets on a grand scale. As we have shifted from the Industrial Age to the Information Age, moving rapidly now into the Virtual Age, we have shifted from creating wealth by exploiting natural resources to doing so via creativity and invention. This shift amplifies the economic importance and impacts of *big ideas*. The Harvard Business School states that "big ideas rank high on a list including technology and intellectual property as sources of competitive advantage."

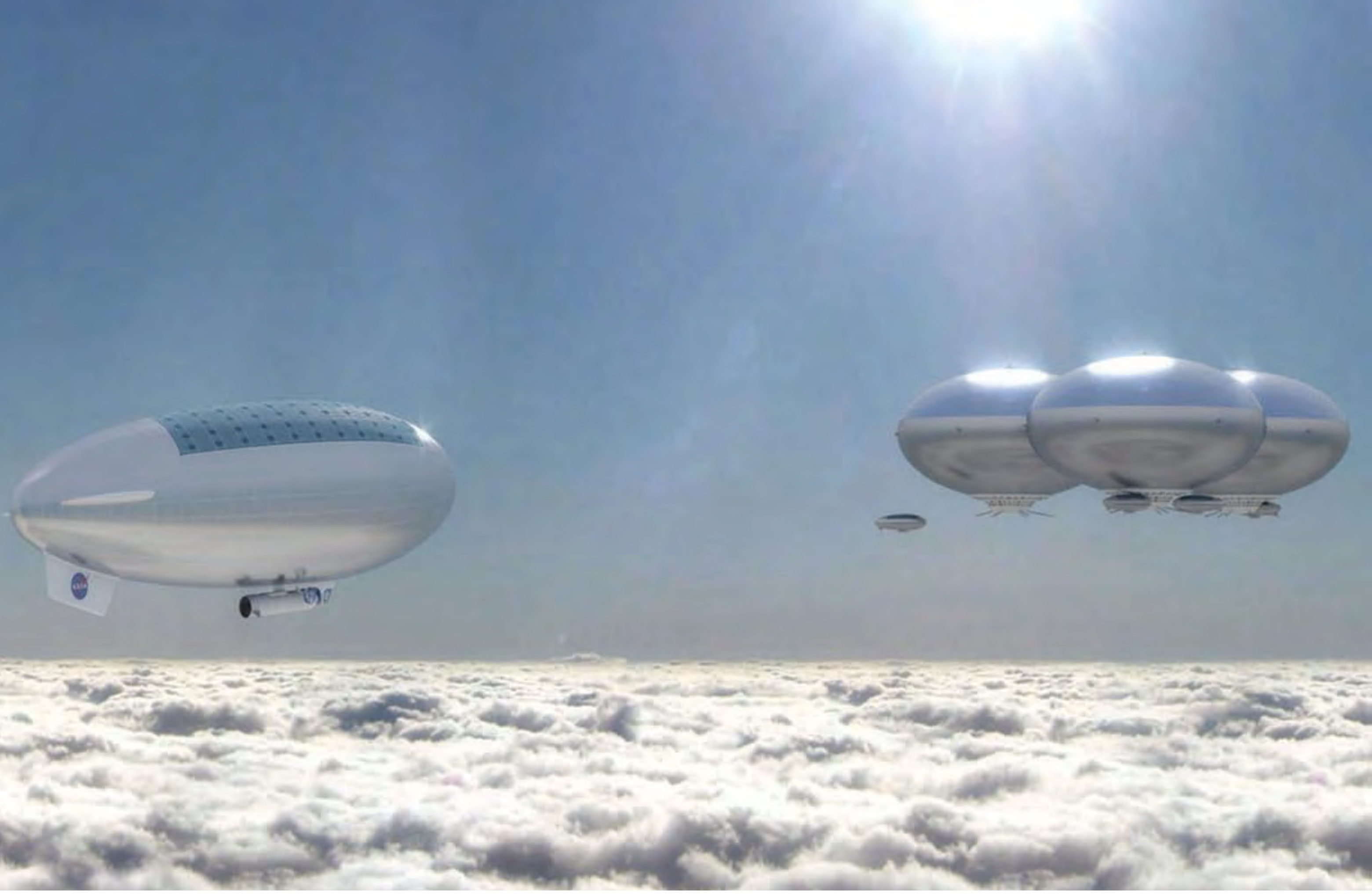
The ongoing development of renewable energy is an example of the criticality of favorable economics for big idea adoption. Although renewable energy approaches are absolutely necessary for climate change mitigation, their development began slowly. Eventually, a combination of improvements in device efficiency, manufacturing approaches and economies of scale brought the costs of this energy nearly to that of the energy derived from fossil fuels, then to parity and then below the costs of conventional fuels in some 65% of the world. These cost reductions have greatly accelerated the growth of renewable sources of energy, far in excess of previous estimates. Renewables now comprise 65% of new generation capacity and 25% of the world's electricity, with ever lower year-on-year costs of generation and storage. Nuclear and coal plants are closing. These cost reductions created favorable economics for transitioning electrical generation to renewables. In this process, energy costs are declining, employment is increasing, climate is mitigated, large numbers are spared a premature death from fossil fuel pollution, and electric aircraft will be recharged with green energy. Also, as all of transportation goes electric, as the batteries improve and we reduce aircraft drag and weight, petroleum as a heavy transportation fuel loses prominence.

There are now two ongoing aerospace big idea revolutions, each with prospective overall market projections in the trillion-dollar range, which should produce a renaissance in aerospace.

Going airborne

One big idea calls for replacing much of today's ground transportation with aircraft. The first step in this revolution centers on uninhabited air systems, or UAS. These aircraft will perform a plethora of societal services, including searching for stranded hikers or boaters; photographing real estate; monitoring pipelines and power lines; delivering consumer packages; and surveilling crime scenes for law enforcement officers. Also coming is on-demand mobility, or ODM for short. These aircraft will pick up and drop off passengers without scheduled flights. For scheduled service, urban air mobility aircraft will replace today's bus and train services. Personal air vehicles will replace automobiles, and these PAVs, in fact, are the largest prospective market. Operating to and from your driveway or street, they would largely obviate traffic tie-ups and, if autonomous, save lives due to reduced traffic accidents. They would mitigate the tremendous infrastructure costs associated with upgrading and maintaining roads and bridges.

The primary enabling technologies for all these classes of vehicles include information technology and artificial intelligence combined with miniaturization and economies of scale and print manufacturing to reduce costs. Numerous companies in the U.S.



and abroad now hope to achieve the ultimate vision of flying safe and affordable electrically powered vertical-takeoff-and-landing craft.

▲ **An artist's rendering** of high-altitude airships with nuclear thermionic avalanche cells, a NASA nuclear battery technology that could power humans on 200-day round trips to Mars.
NASA

Reaching space affordably

The other big idea calls for an order-of-magnitude reduction in the cost of space access. A key enabler is the ongoing effort to create fully reusable rockets. Additional cost reductions would be proffered by incorporating autonomy, artificial intelligence and robotics not just in operating the rockets but in manufacturing them. This would reduce the labor costs that drive much of the high cost of space access. Fuel, for example, makes up less than 1% of space access costs. Addressing manufacturing costs would clear the way for commercializing deep space, establishing colonies and conducting safer, more reliable missions to the moon and Mars, including human missions. Commercial activities in space would no longer end with communications satellites in geosynchronous equatorial orbit. Faster transit times as well as powered entry, descent and landing would be enabled by the availability of low-cost space access. All told, this big idea provides serious economic improvements.

Welcoming creativity

Big ideas are usually longer term, more strategic, broader in scope and enabled by an organizational creative culture. The elements of a creative culture include masses of information, which studies of how humans ideate indicate the subconscious supposedly uses to form and then evaluate quasi-random combinations. When it finds a combination it likes, the subconscious reports back to the conscious when it is not otherwise engaged; walking and when waking up are usual subconscious feedback opportunities. Other creative culture elements include well-defined critical goals, risk embracing, perseverance, independence, multiple solution spaces and triage, toleration of questioning, adequate resources and awards. And, of course, the leaders in particular must also have courage and foresight.

Nascent big ideas and their supporting technologies that are under study at low technology-readiness levels include machine ideation, creativity via an approach similar to that of the subconscious. Machine learning pioneer Stephen Thaler created the "Imagination Engine," wherein he trains a neural net and then isolates this network, lets it "dream," producing quasi-random combinatorials, which are recorded and evaluated systemwise for various applications. This is not creational AI, but rather computational rapid brute force triage of a large number of possibilities. As this technique is developed further it would perhaps be capable of dealing with unknowns, a major need on the road to trusted autonomy, including in the aviation world. Trusted

Innovators continue to encounter a "valley of death" defined as a shortage of support for concepts in the range where risk is largely retired and evaluated and where investors tend to be risk averse.

autonomy would reduce costs and vulnerability to the human factors that are a major cause of safety problems in aeronautics.

Another nascent technology for support of aerospace big ideas would be to apply silicon crystals to passively redirect galactic cosmic radiation away from space travelers or colonists. These crystals have been used for some four decades by the particle accelerator community to redirect up to tera electron volts energy level particles. The millimeter size of these crystals suggests they could even be incorporated into spacesuits to mitigate galactic cosmic radiation. This radiation is quite possibly the greatest hurdle to long-term human space travel and colonization, so this would be an enabler for the big idea of human colonization of Mars.

Then there is the issue of electrical power. The astronauts will need this for in-space propulsion and for on-body transportation at Mars or its moons; to drive the life support equipment on these vehicles and in their planetary habitat; and for in-situ resource utilization.

Revolutionary technology options to replace chemical fuels and solar include positrons, which proffer complete mass to energy conversion, some nine orders of magnitude greater energy density than chemical. The major breakthrough requirement for positrons as an energy source in space is long-term storage, with the state of the art at up to 1,000 minutes.

Another energy storage breakthrough is the NASA nuclear battery technology, called nuclear thermionic avalanche cells, invented by Sang Choi, a senior scientist at NASA's Langley Research Center in Virginia. Nuclear engineers describe the weight efficiency of a nuclear device with a value called the alpha number, defined as how many kilograms of isotope and equipage are needed to produce a kilowatt of power. NTAC has an alpha near 1, compared to values in the 20s for nuclear reactors. This means NTAC is much more weight efficient. Also, NTAC has an energy density of 22 kilowatts/kg of isotope, which is orders of magnitudes higher than energy densities of radioisotope thermal generators. Overall, NTAC is far lighter than reactors and produces far more power than other nuclear battery designs.

NTAC would enable high thrust magnetohydrodynamic propulsion at some 6,000 seconds of specific impulse, a measure of fuel economy, enabling 200-day round trips for a human mission to Mars.

Then there is printing at the nanoscale to produce stable material microstructure to improve various material properties by projected factors of 5 to 10. This would result in lightweight payloads and rockets and therefore greater payload fraction. This material revolution will contribute greatly to inexpensive space access and the big idea of human colonization of Mars among other breakthroughs.

A renaissance in aerospace has begun, thanks to new technologies and leaders in the aerospace industry with the foresight and courage to exploit them. The endgame could well be an ultimate shift to personal air transportation and development of commercial deep space and human space colonization. Despite this progress, today innovators continue to encounter a "valley of death" defined as a shortage of support for concepts at technology readiness levels of 2ish to 4ish, far short of flight readiness. This is understandable, as this is the range where risk is largely retired and evaluated and where investors tend to be risk averse. However, usually there are great learning opportunities in this technology readiness level range, and to the extent creative ideas are allowed to languish and perhaps not be evaluated, many big ideas and their tremendous monetary and other benefits are delayed. Also, many ideas and technologies are delayed because either the enabling technologies or the markets or both were not present. That's why it's always useful to take a fresh look at old ideas given advances in technologies and the changing demands within markets. Reusable rockets were studied and tried experimentally before industry over the past decade took up the task, but the technologies and the requisite support and perseverance were not present. They apparently are in place now.

After many decades of far more evolutionary than revolutionary developments, aerospace — thanks to industrial courage, investments and foresight, the pursuit of big ideas and the ongoing technology revolution — is now on a path to reinvent itself and double market value on both the aero and space sides. Given the major worldwide shifts in economics, the flat technology landscape and the large percentage of research now conducted outside the U.S., this ongoing aerospace renaissance is an object lesson that to compete going forward requires big ideas. As stated, we now create wealth by ideation and invention. ★

Dennis M. Bushnell
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AIAA Bulletin

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Calendar

FEATURED EVENT

21–25 OCTOBER 2019

Washington, D.C.

The 70th International Astronautical Congress (IAC 2019) is where you'll discover the latest capabilities and advancements in space; network with international peers and space leaders across government, industry, and academia; and make critical business connections. Learn more and register today!

iac2019.org

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2019			
8–12 Sep*	Digital Avionics Systems Conference (DASC)	San Diego, CA (http://dasconline.org)	
21–22 Sep*	Amelia Earhart Aerospace Summit	West Layfayette, IN (earhartsummit.org)	
26–27 Sep*	CEAS-ASC Workshop 2019 on Advanced Materials for Aeroacoustics	Rome, Italy (https://www.win.tue.nl/ceas-asc)	
3 Oct–21 Nov	Fundamentals of Space Vehicle Guidance, Control, and Astrodynamics Short Course	Virtual (aiaa.org/onlinelearning)	
21–24 Oct*	International Telemetering Conference (ITC)	Las Vegas, NV (telemetry.org)	
21–25 Oct*	70th International Astronautical Congress	Washington, DC	28 Feb 19
2020			
4–5 Jan	3rd Sonic Boom Workshop	Orlando, FL	
4–5 Jan	Design of Experiments: Improved Experimental Methods in Aerospace Testing Course	Orlando, FL	
4–5 Jan	Design of Electrified Propulsion Aircraft Course	Orlando, FL	
4–5 Jan	Fundamentals of Drones: UAV Concepts, Designs and Technologies Course	Orlando, FL	
4–5 Jan	Missile Guidance Course	Orlando, FL	
5 Jan	Additive Manufacturing: Structural and Material Optimization Course	Orlando, FL	

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

5 Jan	Introduction to Digital Engineering Course	Orlando, FL	
5 Jan	A Unified Approach for Computational Aeroelasticity Course	Orlando, FL	
6 Jan	Class of 2020 AIAA Associate Fellows Induction Ceremony	Orlando, FL	
6–10 Jan	AIAA SciTech Forum	Orlando, FL	11 Jun 19
14–16 Jan*	2nd IAA Conference on Space Situational Awareness	Washington, DC (icssa2020.com)	
21–23 Jan*	International Powered Lift Conference (IPLC 2020)	San Jose, CA (vtol.org/events/2020-transformative-vertical-flight)	19 Aug 19
25–28 Jan*	Aircraft Noise and Emissions Reduction Symposium (ANERS)	Bordeaux, France (Contact: aerospace-europe2020.eu)	31 July 19
27–30 Jan*	66th Annual Reliability & Maintainability Symposium (RAMS®)	Palm Springs, CA (www.rams.org)	
7–14 Mar*	2020 IEEE Aerospace Conference	Big Sky, MT (aeroconf.org)	
10–12 Mar*	23rd AIAA International Space Planes and Hypersonic Systems and Technologies Conference	Montréal, Québec, Canada	22 Aug 19
18 Mar	AIAA Congressional Visits Day	Washington, DC	
23–25 Mar*	55th 3AF Conference on Applied Aerodynamics — "Turbulent Flows in Aerodynamic Applications"	Poitiers, France (http://3af-aerodynamics2020.com)	18 Nov 19
5–7 May	AIAA DEFENSE Forum	Laurel, MD	
19 May	2020 AIAA Fellows Dinner	Crystal City, VA	
20 May	2020 AIAA Aerospace Spotlight Awards Gala	Washington, DC	
25–27 May*	27th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (elektropribor.spb.ru/en/conferences/142)	
15–19 Jun	AIAA AVIATION Forum	Reno, NV	7 Nov 19
23–26 Jun*	ICNPAA 2020: Mathematical Problems in Engineering, Aerospace and Sciences	Prague, Czech Republic (icnpaa.com)	
24–26 Aug	AIAA Propulsion and Energy Forum	New Orleans, LA	11 Feb 20
14–18 Sep*	32nd Congress of the International Council of the Aeronautical Sciences	Shanghai, China (icas.org)	15 Jul 19
26–27 Sep*	CEAS-ASC Workshop 2019 on "Advanced Materials for Aeroacoustics"	Rome, Italy	
12–16 Oct*	71st International Astronautical Congress	Dubai, UAE (mbrsc.ae/iac2020)	
29 Oct–1 Nov*	37th International Communications Satellite Systems Conference (ICSSC 2019)	Okinawa, Japan (kaconf.org)	15 May 19
16–18 Nov	ASCEND	Las Vegas, NV (ascend.events)	

AIAA Continuing Education offerings

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

AVIATION FORUM

From 21–25 June, over 2100 attendees representing a broad range of the aviation community—from across the United States and from 29 other countries—gathered in Dallas for the AIAA AVIATION Forum. The forum included 479 students and 985 technical presentations.


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MAKING AN IMPACT

New NCSU Graduate Award Leads to Fresh Possibilities

Two graduate students pursuing a career in aerospace engineering are receiving invaluable support from the new Dr. Hassan A. Hassan Graduate Award in Aerospace Engineering at North Carolina State University (NCSU).

The inaugural award recipients are Jonathan T. McCready, whose passion for math and physics led him to aerospace after serving in the U.S. Navy, and Josh Glazer, who cites his grandfather, a retired U.S. Air Force aerospace engineer, his freshman advisor, and the university's aerial robotics club for leading him to pursue aerospace engineering.

Presentation of the Dr. Hassan A. Hassan Graduate Award in Aerospace Engineering at the Celebration of Life Luncheon that honored the late Dr. Hassan in May. Pictured, left to right: Dan Dumbacher, President, AIAA Foundation; Johnathan T. McCready; Joshua Glazer; and Dr. Basil Hassan, AIAA President-Elect.

The graduate award was established by Dr. Hassan, an influential aerospace professor at North Carolina State University, shortly before his death on 12 January 2019. The award is designed to entice top NCSU aerospace engineering seniors, who also are AIAA members, to earn their graduate degree (M.S. or Ph.D.) in aerospace engineering at NCSU. In a normal year, there will be one $5,000 award per year. But this year former students, friends, and colleagues raised additional funds in memory of Dr. Hassan so two awards were presented, each for $5,000.

Jonathan McCready

McCready, who calls Kings Mountain, NC, home, began studying criminal justice at the University of North Carolina Wilmington after he finished his service in the U.S. Navy as a master of arms. While he thought criminal justice would be a good continuation of his military training, it wasn't for him.

He wanted to switch to engineering but didn't know if he was good at math. Like many K-12 students, he had struggled with focus. That changed in the military and he quickly discovered he excels at math. "It just took off," he said.

Starting in the fall, McCready will be pursuing a Ph.D. in experimental supersonic aerodynamics and would like to work for a national research lab after graduation.

"Right now, I am in the process of validating the use of fast-response pressure sensitive paint for projectiles traveling at high subsonic and low supersonic speeds using a shock tube I designed to propel projectiles," said McCready, adding he's also using computational fluid dynamics for validation purposes.

He'll be starting work on blast-induced traumatic brain injuries later this fall. The research could help the military better protect soldiers from traumatic brain injuries caused by blast waves due to improvised explosive devices (IED). Currently, there's little in the way of determining, experimentally, flow

McCready with the shock tube he designed to propel projectiles. Above is a different view of the shock tube.

LEFT: Glazer flying a hobby drone with fiberglass reinforced wing

BELOW: Glazer flying a 4k camera drone post collecting wildlife images at the Namibia WAO

properties on the surfaces of free-flight projectiles traveling at high speeds. McCready is working to change that.

Josh Glazer

Glazer, who has lived all over the country, is earning his master's degree. His grandfather worked on a variety of projects for the Air Force, including the A-10 warthog, SR-71 blackbird, X-30 NASP, and the C-17.

NCSU's aerial robotics club helped Glazer narrow which field of engineering he wanted to pursue. "In that club I learned more about aerospace than I ever anticipated as a freshman. It was a bug that bit me and still hasn't seem to let go. All because my adviser gave a little push in the right direction, and a club took the time to teach a freshman who knew nothing."

Glazer is pursuing a career in flight testing because "that's when the real fun starts. All the math is tested in a real situation. I've never been more stressed and more filled with joy than during the maiden flight of a new aircraft."

He's currently conducting research in unmanned vehicle integration and is the lead graduate researcher for the Namibia Wildlife Aerial Observatory (WAO) anti-poaching team. The goal of this research is to use unmanned aircraft to aid anti-poaching efforts in southern Africa.

Both McCready and Glazer are grateful for the award.

"It allows me to remain relatively stress free, with regards to the finances associated with being a graduate student for the first semester," McCready said. "As a result, this lets me put all my focus and attention towards my research."

Glazer said, "the Hassan Award is helping me by allowing me to continue my work on the WAO to end poaching in southern Africa. Without the award I would not have been able to continue in this great program."

For more information about AIAA's educational activities, including making a donation or establishing a new scholarship, please contact Foundation Director Merrie Scott, merries@aiaa.org or visit **www.aiaa.org/foundation**.

On 17 July, AIAA invited congressional stakeholders to a panel on The Global Challenge of Space Traffic Management. The panel addressed some of the important issues involved in defining a framework for a global approach to space situational awareness/space traffic management. The event was organized to introduce these stakeholders to topics that will be discussed at IAC 2019 in October. For more information on related events, go to **iac2019.org/program2019/capitol-hill-events**.

News

AIAA NOS Supports Student Researchers' Flight Investigation of Flame Spread in Microgravity

By Christopher Pestak, AIAA Northern Ohio Section

As part of a continuing effort to encourage students to pursue careers in aerospace, the AIAA Northern Ohio Section (NOS) lent significant volunteer and financial support to a team of student researchers at NASA Glenn Research Center (GRC) who designed and built an experiment to test the effects of vibration on flame spread in microgravity. Research on flame behavior in microgravity is used to improve safety standards for manned spaceflight environments such

as crew capsules and the International Space Station (ISS). The experiment flew on-board the successful launch of Blue Origin's New Shepard suborbital space vehicle on 2 May 2019 (bing.com/videos/search?q=blue+origin+launch&view=detail&mid=A65981388A60AAD043ACA65981388A60AAD043AC&FORM=VIRE).

The student team was led by Evan Rose, a Case Western Reserve University (CWRU) graduate student and student intern with Universities Space Research Association (USRA). Also on the team is Satya Nayagam, a freshman at Princeton University, and Brian Sun, a freshman at Yale University. The students were mentored by AIAA Associate Fellow Dr. Vedha Nayagam and Glenn Lindamood, an electrical engineer at GRC. Both Dr. Nayagam and Mr. Lindamood volunteered many hours in support of the project. Financial and experiment support for the project was provided by AIAA NOS, USRA, and CWRU. The students built the flight experiment at the CWRU Sears think[box]. The Sears think[box] is a public-access innovation center on the campus of CWRU that provides a complete ecosystem for new product development, including everything from design and ideation resources to prototyping and fabrication equipment.

This experiment came into reality after the team's proposal won the Ken Souza Memorial Student Spaceflight

TOP: The student team of (L-R) Evan Rose, Satya Nayagam, and Brian Sun.

BOTTOM: Evan Rose (center) pictured with the team mentors Dr. Nayagam (L) and Mr. Lindamood (R).

Research Competition in 2017. This annual student research competition is supported by Blue Origin and coordinated by the American Society for Gravitational and Space Research (ASGSR) in memory of NASA space biologist Ken Souza. The student team was awarded a payload slot for their experiment on a Blue Origin launch, as well as a grant to develop their concept and build the flight experiment. At the time of the award and through the first year of the project, Satya Nayagam and Brian Sun were still in high school.

The successful flight experiment used the nearly three minutes of high-quality microgravity provided by the New Shepard flight to measure the rate of flame spread across a piece of ashless filter paper fuel (commonly used in microgravity combustion experiments) being oscillated at several different frequencies to show the influence of vibration on flame spread. The data returned from the flight will contribute to the body of knowledge in the area of spacecraft fire safety. Congratulations to Evan, Satya, and Brian on a job well done!

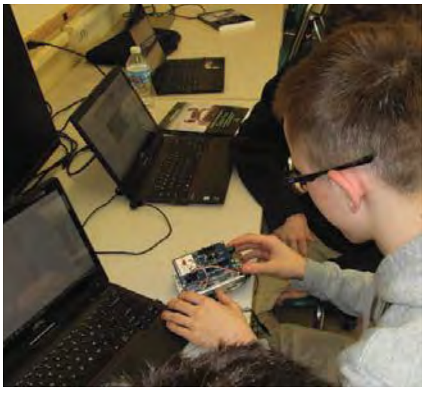
Dr. John Charles received the 2019 AIAA Jeffries Aerospace Medicine and Life Sciences Research Award at the International Conference on Environmental Systems in Boston. Dr. Charles was recognized for excellence in biomedical research, scientific leadership, and international cooperation, leading to significant contributions to our understanding of the challenges of long duration human spaceflight. The award was presented by Dr. Daniel Barta.

2018-2019 AIAA SSTC-STTC STEM Teacher Grant Program Awards

By John Bloomer, AIAA Space Systems Technical Committee

For a tenth consecutive year, the AIAA Space Systems Technical Committee (SSTC) and Space Transportation Technical Committee (STTC) have partnered to award grants to K-12 STEM teachers through a nationwide competitive process, providing STEM resources to stimulate student imagination and confidence. For the 2018-2019 school year, three $500 grants were awarded, made possible through donations from NASA Alumni League JSC Chapter, San Fernando Engineers' Council, and Analytical Mechanics Associates, Inc. This year's winning teachers brought forward projects leveraging robotics, model rocketry, and a nursery rhyme-oriented STEAM textbook, giving students motivation and hands-on experience foundational to future careers.

Jolene Esz, Archbishop McNicholas High School, Cincinnati, OH – Ms. Esz's high school juniors and seniors explored robotics engineering using BOE Shield-bots as a new addition to their Intro to Engineering module on hands-on electronics. The module is geared toward learning to identify basic electronics components, using a multimeter, building circuits, and working with Ohm's Law. The purpose of adding the robots was to give students a chance to create circuits and use them in a more "real world" way. Students constructed the robots and designed their own circuits for battery life indicator and touch sensors. They also learned to write code for the robot Arduino (C++) board to correctly use the sensors. While the robot and circuit build phases of the project went smoothly, the software phase introduced an unexpected lesson in real-world engineering challenges. When the time came to test their robot sensors, connectivity to the web-based Arduino control interface could not be established. The students worked methodically to rule out candidate root causes (e.g., errors in robot construction, failed USB connectivity, bad power supply), finally establishing that root cause was a group policy IT issue. The project gave students a taste of how real engineering projects go. They had to have disciplined up-front planning to maximize their chances for success, and they had to apply their troubleshooting and critical thinking skills when circumstances drove them off-plan.



Mari Koester, St. John's Lutheran School, Denver, CO – Ms. Koester's uniquely collaborative project "To Infinity and Beyond" used model rocketry to introduce kindergarteners to the exciting world of STEM while providing 8th graders leadership experience. Each eighth grader built an Estes model rocket, while encouraging a kindergarten buddy to help with age-appropriate steps of the process. The younger students learned how a rocket moves, meshing with the kindergarten Next Generation Science Standards (NGSS) unit of forces and interactions. The 8th graders exercised the important leadership skills of critical thinking, collaboration, and communication. The teams demonstrated all 22 rockets at a launch event attended by students, staff, and parents, promoting excitement for STEM across the whole school community.

Meg Draeger, Chaminade Julienne Catholic High School – CJ STEMM Center, Dayton, OH – Ms. Draeger's project created a set of nursery rhyme-oriented activity kits based on the book *Hands-On STEAM Explorations for Young Learners* by Allison Bemiss (Prufrock Press). The kits included supplies and picture books necessary to conduct STEAM challenge sessions. The project's lead educator/engineer partnered with 11 teachers at local schools to cofacilitate sessions for nearly 300 K-3 students. Children worked in teams to define hypotheses, conduct experiments, and apply the engineering design process to arrive at a solution. Using picture books as a basis for describing scientific and engineering work proved a successful way to engage students and get them excited about future occupations. The 45-minute sessions had students working with their minds, hands, and simple materials, and involved absolutely no electronics or computer technology. The successful project will be carried into the next school year and featured at a summer educators' workshop.

Sixteen AIAA Diversity Scholars had the opportunity to attend the 2019 AIAA AVIATION Forum held 21–25 June in Dallas, TX. These students had a chance to check out AIAA Student Day, technical presentations, plenary and Forum 360 sessions, and network with a variety of aerospace professionals. Thank you to Aurora Flight Sciences for sponsoring the students.

Obituaries

AIAA Fellow Hazen Died in April

Photo by Orren Jack Turner

David C. Hazen, Princeton alumnus and professor of mechanical and aerospace engineering, emeritus, died on 27 April. He was 91.

Hazen graduated from Princeton University in 1948 and earned his master's in 1949, before he joined the faculty in the newly formed aeronautical engineering department. He was appointed full professor in 1963. He served as associate dean of the faculty from 1966 to 1969 and was associate chair of the Department of Aerospace and Mechanical Sciences from 1969 to 1974. He transferred to emeritus status in 1982 after 33 years of service.

From 1975 to 1977 at the conclusion of the Vietnam War, Hazen served as chairman of the Naval Research Advisory Committee (NRAC). For his work with NRAC, Hazen received the Distinguished Public Service Award and was praised for his "dedication, hard work, and scientific competence and knowledge."

Throughout his academic life, Hazen was involved with naval research on low-speed flight and conducted much of this research in an experimental wind tunnel lab created at Princeton's Forrestal Campus, as well as with the help of Navy blimps used to suspend model aircraft to test aerodynamics at slow speeds. In an era where the industry was pushing flight faster and higher, Hazen's contributions to the research of aeronautical engineering were in the area of low-speed aeronautics and aerodynamics. Hazen's work helped to optimize aircraft at low speeds to make planes safer to land and forged the way for the shorter runways common today. This allowed airports to be closer to major cities and increased the number of flights per day to take off.

Hazen was also involved in promoting aeronautical engineering education worldwide, and he traveled to Kanpur, India, during academic year 1964–1965 as part of a delegation from nine American universities designated to help the Indian government establish the Indian Institute of Technology. He and two of his graduate students helped to found India's first Department of Aeronautical Engineering, supervising the construction of experimental facilities complete with flight-test laboratories and convening technical staff for the instructional laboratory program. He also assisted in the development of the engineering school at the University of Jordan.

AIAA Fellow Ericsson Died in June

Dr. Lars Eric Ericsson, 94, passed away on 2 June 2019. The aerospace community has lost a pioneering scientific powerhouse who made many groundbreaking contributions to unsteady aerodynamics and design of flight vehicles. He worked on launch vehicles, space shuttle, re-entry vehicles, helicopters, aircraft and missiles.

Dr. Ericsson's career spanned more than six decades following his graduation from the Royal Institute of Technology (KTH) in Stockholm, Sweden, in 1949. He began his professional career in Sweden working for the Aeronautical Research Institute (FFA) and the Swedish Aircraft Company (SAAB) and then later for Lockheed Aircraft Corporation and Lockheed Missiles and Space in the United States.

Initially, he directed aerodynamic research necessary for the conversion of the Swedish double-delta fighter to a Mach 2 aircraft, following which he worked in senior engineering positions with Lockheed Missiles and Space Company. Here he developed analytical methods and subsequently directed aerodynamic research that would lead to prediction of aeroelastic characteristics of Saturn-Apollo launch vehicles, the Space Shuttle Launch Vehicle, and Atlas-Agena ascent vehicles. His extensive experience in re-entry vehicle unsteady aerodynamics included developing stability criteria for the Polaris re-entry system, and extension to tactical missile systems. He became recognized as the leading authority on unsteady separated flows. His penetrating analyses of nonlinear aerodynamics and dynamic stall characteristics of airfoils and slender axisymmetric bodies became the basis for studying combat aircraft unsteady aerodynamics and nonlinear dynamics. More recently, he directed aerodynamic research developing analytic methods to determine the aeroelastic characteristics of the Space Shuttle cable trays, which led to modifications of the launch vehicle to protect the cable trays from high-velocity cross-flow, subsequently validated in wind tunnel tests. Much of this work was supported by his prominent role in a number of international collaborative working groups.

After he retired from Lockheed Missiles and Space Company in 1991, he became affiliated with Nielsen Engineering and Research and worked for many years as a consultant for research in unsteady aerodynamics and structural dynamics, while continuing to elucidate diverse problems ranging from the nonlinear aerodynamics of wind turbines, to viscous motion coupling in combat aircraft maneuvers. What these problems all had in common was complexity of the nonlinear unsteady aerodynamic phenomena. These contributions came largely before the age of large-scale CFD, when physics-based and phenomenological analysis was the only recourse to come to grips with thorny unsteady aerodynamics problems of the day. Even today, his analytical approach based on flow physics concepts remains a valuable tool in preliminary prediction of unsteady turbulent phenomena that defy routine numerical simulation.

Dr. Ericsson retired once more in 2003. Over his long career he received a number of degrees, commendations, awards and honors including: 1972 Ph.D. from KTH, 1979 formal thank you letter from Martin Marietta for work on the aeroelastic stability analysis of the External Tank LO2 Cable Tray, 1983 Robert E. Gross Award Finalist Lockheed Missile Systems Division, 1984 AIAA Fellow, 1984 AIAA Aerodynamics Award, 1985 Robert E. Gross Award Recipient Lockheed

Missile Systems Division, and 1989 Certificate of Merit for 30 years of service to the Fleet Ballistic Missile Program. He reviewed and edited professional journals for many years, including the AIAA *Journal of Aircraft*, and he was a member of the AIAA Atmospheric Flight Mechanics Technical Committee, as well as being a member of the American Helicopter Society.

The profound contribution Dr. Ericsson made to the field is evidenced by the huge body of published work he left behind, which constitutes an invaluable source of references for those who wish to cultivate something of his instinctive feel for the sometimes maddening complexity of turbulent flow physics. His enduring legacy is one of prolific achievements of a brilliant researcher driven by an unmatched enthusiasm and instinct to discover, whose human qualities of kindness and humility were always part of him.

AIAA Fellow Guastaferro Died in June

Angelo "Gus" Guastaferro, aerospace executive, passed away on 9 June. He was 87 years old.

Mr. Guastaferro earned a B.S. degree in Mechanical Engineering from the Newark College of Engineering, an MBA from Florida State University, and Diplomate of the Advanced Management Program from Harvard University. After three years in the U.S. Air Force, he joined NASA for a distinguished career in space programs for 22 years, including Deputy Manager on the Viking program at Langley, Director of Planetary Programs in Washington, DC, and Deputy Director of Ames Research Center in Mountain View, CA. He later became a Vice President and Executive Director at Lockheed Missiles & Space in Sunnyvale, CA. Returning to Virginia, he joined nView Corporation, becoming CEO and Chairman of the Board.

AIAA Senior Member Simmons Died in July

Larry L. Simmons died on 19 July 2019.

Simmons attended Furman University for one semester before enlisting in the U.S. Air Force in 1951. He was stationed at several bases including Lackland Air Force Base; Sheppard AFB; Parks College of Aeronautical Technology (IL); Chanute Field (IL); Smirna AFB (TN); Portland AFB (OR); Ashia AFB (Japan & Korea); and March AFB (CA). He left the air force in December 1954.

Simmons continued his education at Clemson University from 1955 to 1959, earning a degree in Electrical Engineering (BSEE). Upon graduation he relocated to California to Northrop Aircraft to pursue a career in the nation's emerging space program.

He became a California Registered Professional Engineer and at the time of his retirement in 2003, Simmons was the Senior Principal Engineer/Scientist at Boeing Company (formally McDonnell-Douglas Corp.) in Huntington Beach, CA, specializing in the design of missile/rocket guidance, navigation and control systems. Among his projects were the guidance systems for the Space Shuttle Enterprise, the Boeing Delta II, Delta III and Delta IV satellite booster/launch rockets. Among his proudest moments were his successful launches of NASA's Martian mission and the Apollo moon landing.

AIAA Honorary Fellow Kraft Died in July

Chris Kraft, who helped shape the success of NASA's manned space missions in the 1960s as the godfather of the ground-based Mission Control organization, died 22 July. He was 95.

Kraft enrolled in the mechanical engineering program at Virginia Tech in 1941 before switching to aeronautical engineering, a new discipline at the school. After graduating in December 1944 on an accelerated wartime schedule, he went to work at the National Advisory Committee for Aeronautics (NACA) flight research division at Langley, VA.

He was assigned to the Flight Research Division where among other projects he served as project engineer on flying-qualities investigations of the P-51H. He also conducted analytical work on gust alleviation, and directed a pioneering study of potentially dangerous wake turbulence caused by trailing vortices. In the 1950s he was the project engineer on flight tests of the Navy's high-priority Vought F8U Crusader, which exhibited numerous problems in its earliest versions. Because of the work that Kraft and his coworkers did at Langley, the F8U was subsequently redesigned and was an outstanding fighter during the Vietnam War.

In 1958, he joined the NASA Space Task Group as NASA's first flight director. He created the mission planning and control processes required for crewed space missions in areas as diverse as go/no-go decisions, space-to-ground communications, space tracking, real-time problem solving and crew recovery. During the Apollo program, Kraft became the Director of Flight Operations at Manned Spacecraft Center, responsible for overall human spaceflight mission planning, training and execution. His leadership in this critical area continued through the Apollo 12 mission in 1969, at which time he became deputy director of the center. He served as the center director from January 1972 until his retirement in August 1982, playing a vital role in the success of the final Apollo missions, the Skylab crewed space station, the Apollo-Soyuz Test Project and the first flights of the space shuttle.

After his retirement, Kraft consulted for numerous companies including IBM and Rockwell International. In 1994 and 1995, he led a NASA review team that recommended handing space shuttle operations over to a private contractor.

In 2001, he published an autobiography entitled *Flight: My Life in Mission Control*. He received numerous awards and honors for his work, including the NASA Outstanding Leadership Medal; four NASA Distinguished Service Medals; the Distinguished Alumnus Citation from Virginia Tech in 1965; the Hampton, VA, Distinguished Citizen Award in 1966; the John J. Montgomery Award in 1963; the National Space Club Goddard Memorial Trophy in 1979; and the 1996 John F. Kennedy Astronautics Award. In 1999, he was presented the Rotary National Award for Space Achievement and in 2006, NASA honored him with the Ambassador of Exploration Award. In addition, in 2011, NASA named its Building 30 Mission Control Center at the Johnson Space Center in his honor.

AIAA Fellow O'Brien Died in July

Walter F. O'Brien Jr., the J. Bernard Jones Professor of Mechanical Engineering, died on 25 July. He was 82.

Professor O'Brien received his B.S. and Ph.D. from Virginia Tech in 1960 and 1968, respectively, and he earned his M.S. from Purdue University. He taught as an assistant, associate, and professor of mechanical engineering, and in 1987 he was a visiting scientist in the Aero Propulsion Laboratory at Wright-Patterson Air Force Base. In 1990 he was appointed associate dean for Research and Graduate Studies for the College of Engineering, and he was one of the founding Associate Deans of the Virginia Consortium of Engineering and Science Universities. In 1993 he was named head of the Department of Mechanical Engineering where he served until 2004. In 2002 he chaired a successful multi-university proposal to found the National Institute of Aerospace (NIA).

Over the course of his 52 years at Virginia Tech, O'Brien supervised the graduate work of over 130 M.S. and Ph.D. students, and published more than 150 technical papers and journal articles in the field of propulsion. He was the first Virginia Tech mechanical engineering professor to establish an identifiable research group, the Gas Turbine Research Institute, which he did as a junior faculty member. The effort marked a turning point in the department's evolution from a well-respected regional teaching faculty into a nationally recognized research power.

O'Brien's extensive list of accomplishments included being named Fellow of ASME and AIAA. He received the SAE's Teetor Award as an Outstanding Engineering Educator, ASME's Dedicated Service Award, and a Virginia Tech Outstanding Teaching Award. In 2003, he received the Virginia Joint Engineering Society's Pletta Award as the Outstanding Engineering Educator in the state of Virginia. In 2012, he received AIAA's Air Breathing Propulsion Award "for outstanding technical contributions, creativity, and generosity that have inspired hundreds of students to achieve bright careers in gas turbine and high-speed propulsion."

AEROSPACE ENGINEERING AND MECHANICS AEROSPACE STRUCTURES AND ADVANCED MATERIALS, UNIVERSITY OF MINNESOTA

The Department of Aerospace Engineering and Mechanics (AEM) seeks to fill one tenure-track faculty position in Aerospace Structures and Advanced Materials (ASA). Researchers engaged in the development and application of modern experimental methods in ASAM are particularly encouraged to apply. Current research in the AEM department includes the development of nanoscale mechanics (molecular dynamics, lattice statics, quasicontinuum method, applied quantum mechanics) and continuum mechanics (phase transformations, phase field models, micromagnetics, stability and bifurcation) for the understanding and discovery of advanced materials and structures. The AEM department has close ties with on-campus multidisciplinary centers, and convenient access to outstanding shared experimental and computational facilities, such as the Minnesota Nano Center, the Characterization Facility, the Center for Magnetic Resonance Research, and the Minnesota Supercomputing Institute. Information about the department is available at **https://cse.umn.edu/aem**

Applicants must have an earned doctorate in a related field by the date of appointment. The successful candidate is expected to have the potential to conduct vigorous and significant research programs and the ability to collaborate with researchers with a wide range of viewpoints from around the world. This candidate will participate in all aspects of the Department's mission, including (I) teaching undergraduate and graduate courses to a diverse group of students in aerospace engineering and mechanics; (II) participating in service activities for the department, university, broader scientific community, and society; and (III) supervising undergraduate and graduate students and developing an independent, externally-funded, research program.

The intent is to hire at the assistant professor rank. However, exceptional applicants may be considered for higher rank and tenure depending upon experience and qualifications. It is anticipated that the appointment will begin fall 2020.

The AEM department is committed to the goal of achieving a diverse faculty as a way to maximize the impact of its teaching and research mission. The University of Minnesota provides equal access to and opportunity in its programs, facilities, and employment without regard to race, color, creed, religion, national origin, gender, age, marital status, disability, public assistance status, veteran status, sexual orientation, gender identity, or gender expression. To learn more about equity & diversity at UMN, visit **diversity.umn.edu**.

To be considered for this position, candidates must apply on-line at: **https://humanresources.umn.edu/jobs** and search for Job ID No. 331546 or visit: **https://z.umn.edu/4fu6**

Please attach your: 1) cover letter, 2) detailed resume, 3) names and contact information of three references, and 4) a statement of teaching and research interests as one PDF.

Application Deadline: The initial screening of applications will begin on **November 1, 2019**; applications will be accepted until the position is filled.

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

1919

Sept. 11 Hale war rockets are declared obsolete for the British Army. The stickless, spin-stabilized rockets were invented in 1844 by Englishman William Hale and deployed throughout the latter half of the 19th century and eventually replaced the stick-stabilized Congreve rockets introduced during Napoleonic times. Frank H. Winter, **The First Golden Age of Rocketry — Congreve and Hale Rockets of the Nineteenth Century**, pp. 223-224.

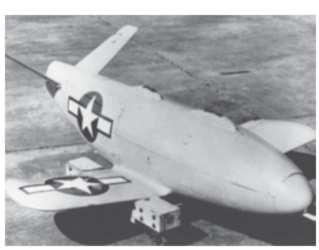
Sept. 16 The first radio message from an aircraft in flight to a submarine is transmitted in a test at Fishers Island, New York. **Aircraft Year Book, 1920**, p. 256.

Sept. 26 The Army undertakes the third series of tests of the Kettering Aerial Torpedo at Carlstrom Field, Arcadia, Florida. The torpedoes are launched 14 times from a trolley car sliding along crudely made rails. The second series was at Long Island, New York, late in 1918 with one success in four tries. At Carlstrom, five torpedoes become airborne. The last flies some 25 kilometers, the longest flight of the torpedo. Kenneth P. Werrell, **The Evolution of the Cruise Missile**, pp. 12-16, 26-30, 235.

1944

Sept. 1 The first air-launched V-1 flying bombs, carried by Heinkel He 111 aircraft, fall in East Anglia, England; in effect, these are the first air-launched cruise missiles. F.K. Mason and M. Windrow, **Know Aviation**, p. 48.

Sept. 4 The Germans stop their V-1 attacks on Great Britain from across the English Channel, mainly because British defenses and countermeasures against the weapon have been so effective. Of 8,000 V-1s launched, 29% got through to London. However, as of Sept. 1, the Germans have deployed the V-1 against continental European targets, mainly upon Brussels, Antwerp and Liege, in their attempts to strike at Allied resupply centers. **Flight**, Sept. 14, 1944, p. 292.



Sept. 6 A contract for development of the Gargoyle, a rocket-boosted, radio-controlled anti-ship glide bomb missile for use with carrier-based aircraft, is awarded by the U.S. Navy to McDonnell Aircraft. The project is prompted by the success of Germany's Hs 293 glide and SD 1400 high-angle bombs. The 4,448-newton (1,000 pound) thrust propulsion of the missile is subcontracted to the recently created Aerojet Engineering. F.I. Ordway III and R.C. Wakeford, **International Missile and Spacecraft Guide**, pp. 118-119.

Sept. 8 The German A-4 rocket, also known as the V-2, is fired for the first time in combat, in a suburb of Paris. A few hours later a second rocket is sent against Chiswick, in London, killing two people and injuring 10. E. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 48.

Sept. 10 The Fairchild C-82 Packet, the first U.S. military aircraft designed as a transport, makes its first flight. Powered by two Pratt & Whitney R-2800 2,000-horsepower air-cooled engines, the C-82 is an easily recognizable aircraft because of its unique twin-boom design and large, boxy, unencumbered center section that allows cargo to be loaded at the rear. Kent A. Mitchell, **Fairchild Aircraft, 1926-1987**, pp. 122.

Sept. 14 Flying a Douglas A-20, U.S. Army Air Corps officers Col. Floyd Wood, Maj. Harry Wexler and Lt. Frank Reckord make the first flight into a hurricane in order to obtain scientific data. E. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 48.

During September 1944

• A Curtiss SB2C-1C Helldiver, fitted with two 20-mm cannons mounted in the wing instead of the standard four .50-caliber machine guns of other versions, becomes the first cannon-armed carrier-based dive bomber flown in combat. Peter Bowers, **Curtiss Aircraft, 1907-1947**, p. 426.

• Nineteen-year-old Stanley Hiller Jr. becomes the first Californian with a helicopter license when the Civil Aeronautics Board grants him an experimental license for his self-designed and built coaxial Hiller XH-44 "Hiller-Copter," which he first flew from the stadium field at the University of California at Berkeley. **Aero Digest**, Sept. 1, 1944, p. 153.

• Group Capt. Frank Whittle, inventor of the first British jet engine for aircraft, is promoted to acting air commodore. He will stay on special duty with power jets to develop his engines further. **The Aeroplane**, Sept. 22, 1944, p. 323.

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1969

Sept. 4 British aviator Sheila Scott takes off from London's Heathrow Airport on the second of her round-the-world solo trips, flying a Piper Comanche aircraft. On the same day, she arrives at the British Royal Air Force base at Luqa, Malta, and from there heads to Khartoum, Sudan, and then to Nairobi, Kenya, arriving on Sept. 6. **Flight International**, Sept. 11, 1969, p. 403.

Sept. 6 Apollo 8 astronauts Frank Borman, James Lovell and William Anders are named recipients of the Harmon International Astronaut Trophy for their December 1968 mission that was the first manned spaceflight to the moon and back. **Washington Star**, Sept. 7, 1969, p. A7.

Sept. 12 NASA begins the distribution of about 8.2 kilograms of lunar rocket samples to 106 U.S. scientific investigators and 36 in eight other countries for scientific analyses. A small portion of samples is made available for public display. Preliminary examinations disclose that there are two basic rock types: compacted lunar soil and igneous rocks. The igneous rocks had crystallized from 3 or 4 billion years ago. Tests on animal and plant life has shown no ill effects. **NASA Release 69-130**; **Washington Post**, Sept. 17, 1969, p. B1.

Sept. 15 The prototype of Cessna's 500 Citation twin-engine, turbofan-powered small business jet completes its first test flight. The 500 Citation will go on the market in 1972 and become one of Cessna's most successful and widely used aircraft. The 7,000th model will be delivered by July 2016 and some 35 million flight hours will be logged. (In 1976, the aircraft was upgraded and became known as the Citation I.) The aircraft has a maximum speed of 643 kph and a range of 2,092 kilometers. **Aviation Week**, Sept. 22, 1969, p. 28.

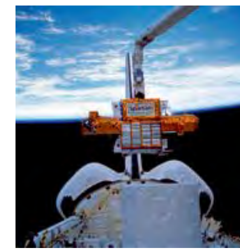
Sept. 18 The U.S. Post Office announces a delay in the delivery of the Apollo 11 moon landing stamps because of an "unprecedented number of requests ... from people all over the world." NASA, **Astronautics and Aeronautics, 1969**, p. 311.

Sept. 18 Vikram Sarabhai, chairman of the Indian Space Research Organization, and NASA Administrator Thomas O. Paine sign an agreement on an experiment to broadcast educational TV programs from NASA's planned ATS-F (later known as the Applications Technology Satellite 6, or ATS-6) to 5,000 small Indian villages for a year. This is to be the world's first educational satellite as well as the first experimental direct-broadcast satellite. NASA, **Astronautics and Aeronautics, 1969**, pp. 310-311; NASA, **Astronautics and Aeronautics, 1974**, pp. 238, 258.

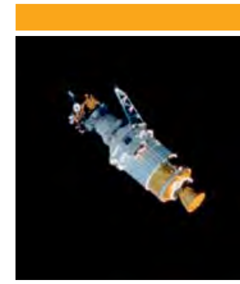
Sept. 23 The Fédération Aéronautique Internationale (the International Aeronautical Federation or FAI) awards its Gold Medal, its highest honor, to NASA test pilot Joseph Walker for "his many enduring contributions to the advancement of aviation made during a 21-year flight research career marked by extraordinary perfection and valor." His widow accepts the award in a ceremony at Edwards Air Force Base, California. As the Edwards Flight Research Center's chief research pilot, Walker flew the X-15 to its highest altitude (107.8 kilometers) and therefore into space; he was the first man to fly the lunar landing research vehicle astronaut training craft; he taught Apollo 11 commander Neil Armstrong at the center and was the author of 20 technical papers and articles. NASA, **Astronautics and Aeronautics, 1969**, p. 315.

During September 1969
A Rocketdyne high-thrust, liquid-propellant rocket engine produces a 500-second specific impulse during a test firing. The firing is made at a simulated altitude of 15,240 meters in a vacuum chamber and the engine uses liquid lithium and hydrogen as fuels and liquid fluorine as the oxidizer. Specific impulse is a standard measure of rocket engine efficiency, and the Saturn J-2 rocket engine for Project Apollo and produced by Rocketdyne delivers approximately 425 seconds of specific impulse. **Aviation Week**, Sept. 8, 1969, p. 20.

1994



Sept. 9 Space shuttle Discovery STS-64 is launched. The six-person crew immediately begins a series of experiments, including deploying and retrieving the SPARTAN, short for Shuttle Pointed Autonomous Research Tool, to study solar wind. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 565.



Sept. 16 The Ulysses probe is the first spacecraft to fly over the sun's south pole, scientists announce. The joint project of the European Space Agency and NASA will end in June 2009 after completing the first survey of the sun's environment in space from the equator to the poles. It will collect the first detailed measurements of the solar wind from the sun's polar regions at solar minimum and solar maximum and discover energetic particle "reservoirs" surrounding the sun. **Reuters**, Sept. 16, 1994; ESA, **Ulysses fact sheet**.

JOSHUA LEE, 29

U.S. Air Force captain and deputy branch chief, Weapon Dynamics, Guidance, Navigation and Control Branch, U.S. Air Force Research Laboratory Munitions Directorate; Eglin Air Force Base, Florida

Joshua Lee spent his childhood in Massachusetts, New Jersey and South Carolina as the son of a U.S. Coast Guard mechanic who taught him how to fix things. As an Air Force officer and engineer, Lee has worked on F-22s at Wright-Patterson Air Force Base in Ohio and built drones at Eglin. Now, Lee helps manage AFRL sections responsible for ensuring weapons fly safely to their intended targets, networking various weapons and research and development of drones.

How did you become an engineer?

Spending time with my dad, who was in the Coast Guard for 21 years, I learned to fix things and look at things from a technical standpoint. I even removed my own training wheels because he was deployed at the time. In high school, I was good at math and technical problem solving. Because my dad was enlisted, we didn't have a lot of money. I got an Air Force ROTC scholarship, went to Clemson University and got my undergraduate degree in mechanical engineering. After college, I was in the F-22 program office, working on the environmental control system that cools the electronics and also cools and provides oxygen to the pilot. The Air Force sent me to get my master's degree in aeronautical engineering at the Air Force Institute of Technology at Wright-Patterson. Then, I got blessed with being able to move down to Eglin. For my first two years here, I was the weapon airframe flight test lead. We designed, built and tested new UAV systems to meet weapon requirements. Now I'm helping to develop weapons technology, including making sure the weapon can get to its target and networking quadrotors and bigger drones to fly together in formation.

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

I like to think we're going to go to more autonomous flight, where freight aircraft are essentially UAVs that fly completely on their own. I like to think that eventually the airlines can get to pure autonomous flying, almost like a subway line with no conductor on board. Because of that, I think you're going to see a large increase in general aviation. As far back as Icarus in Greek mythology, people dreamed of flying. That's never going to change. People will still want to fly their own planes. I think it's going to actually pull more people into it. The demand will go up and hopefully the cost goes down. ★

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