AEROSPACE
★ ★ AMERICA ★ ★ ★

THE CHOICE

The designs and backstory underlying the U.S. Navy's unmanned tanker competition

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AIAA
Shaping the Future of Aerospace

MAY 2018 | A publication of the American Institute of Aeronautics and Astronautics | aerospaceamerica.aiaa.org

U.S. Air Force

AIAA/IEEE ELECTRIC AIRCRAFT TECHNOLOGIES SYMPOSIUM

12–13 JULY 2018 | DUKE ENERGY CONVENTION CENTER, CINCINNATI, OH

The aerospace industry has set ambitious goals for the next three generations of commercial transport aircraft to accommodate rapid growth in emerging markets and ensure the future sustainability of air travel. One approach being explored to meet these targets is nontraditional aircraft propulsion using electric, turboelectric, or hybrid-electric powertrains.

Recent workshops by the IEEE and AIAA have identified the need to bring together electrical engineers and aerospace experts as the industry looks to more electric propulsion technologies for future aircraft. The AIAA Aircraft Electric Propulsion and Power Working Group, the IEEE Transportation Electrification Community, and the College of Engineering of the University of Illinois at Urbana-Champaign are collaborating to organize a new two-day symposium to address these issues. The event occurs on 12–13 July, following the AIAA Propulsion and Energy Forum.

TECHNICAL PROGRAM

The symposium will focus on electric aircraft technology across three programmatic tracks with more than 70 papers:

1. Electric-power enabled aircraft configurations and system requirements
2. Enabling technologies for electrified aircraft propulsion
3. Electric aircraft system integration and controls.

KEYNOTE SPEAKERS

Jay Dryer
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SYSTEM ENGINEERING NEEDS AND CHALLENGES GENERATED BY ELECTRIFICATION OF AIR VEHICLES

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AEROSPACE AMERICA

MAY 2018, VOL. 56, NO. 5

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MANUFACTURING AND DISTRIBUTION
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Aerospace America (ISSN 0740-722X) is published monthly except in August by the American Institute of Aeronautics and Astronautics, Inc., at 12700 Sunrise Valley Drive, Suite 200 Reston, VA 20191-5807 [703-264-7500]. Subscription rate is 50% of dues for AIAA members (and is not deductible therefrom). Nonmember subscription price: U.S., $200; foreign, $220. Single copies $20 each. Postmaster: Send address changes and subscription orders to Aerospace America, American Institute of Aeronautics and Astronautics, at 12700 Sunrise Valley Drive, Reston, VA, 20191-5807, Attn: A.I.A.A. Customer Service. Periodical postage paid at Reston, Virginia, and at additional mailing offices.

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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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Henry Canaday

A former energy economist, Henry has written for Air Transport World, Aviation Week and other aviation publications for more than two decades.

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Jan Tegler

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

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DEPARTMENTS

MQ-25's most fundamental requirement

▲ **Lockheed Martin Skunk Works** is one of the companies competing to build the U.S. Navy's MQ-25. This is a Lockheed Martin illustration.

More is at stake in the U.S. Navy's initiative to build a fleet of unmanned tanker aircraft than the program's tactical goals.

Those managing and overseeing the MQ-25 program have the burden of restoring faith that the Pentagon and its contractors can develop amazing flying machines at something close to their advertised costs. That's the unspoken requirement.

Building a tanker fleet marks a step back from the original vision of a fleet of stealthy, carrier-based unmanned combat planes that would take off from aircraft carriers and do much of what stealthy F-35Cs will soon do.

The bolder vision was buttressed by years of test flights with unmanned experimental planes. Everything seemed to point toward a future in which crews would supervise autonomous combat planes from the safety of ground stations or ships, rather than pilots risking their lives flying into enemy airspace and back. The vision seemed like a logical step in the progression from the days when pilots in biplanes chose to jump to their deaths rather than burn up with their aircraft (see Looking Back, Page 62, May 19, 1918).

What has deflected us from this next step is not a particular technological hurdle or even the supposed cultural reluctance to take away jobs performed valiantly today by human pilots. What has deflected us is a seeming inability to accurately predict the cost of developing, manufacturing and sustaining a fleet of complex aircraft.

As this month's cover story shows, affordability and schedule were on the mind of then-Deputy Defense Secretary Robert O. Work when he made the decision in 2015, in coordination with the Navy, to set the service on a course to acquire what would primarily be a fleet of unmanned tanker aircraft.

Rather than be disappointed by this twist, the wisest course for congressional advocates of unmanned flight might be to focus oversight efforts on whether the MQ-25's $5 billion cost ceiling is realistic and, if it is, whether the Navy and the winning contractor have a sound plan to live within it.

Put simply, the Pete Townsend rule should apply here: "…don't get fooled again." Of course, it's rare that a broken budget and schedule can be attributed entirely to an overly rosy prediction. The Navy, according to the Government Accountability Office, wants to "develop and evolve" the MQ-25 to possibly carry weapons. If managers and congressional overseers are not careful, that strategy could set the stage for "requirements creep." That's the term for the tendency of well-meaning people to layer on new demands over the course of a program. Adding to the temptation could be the stealthy attributes in some of the competing designs, features that are leftovers from the Navy's bolder vision and that do not stem from the MQ-25 requirements. Designing the MQ-25 with expanded roles in mind could amount to incorporating expensive, hard-to-manufacture elements without a guaranteed return on investment.

The best course here might be to accept that the proposed mission for the MQ-25 is consequential enough. Getting these planes out the door on schedule and on budget would deliver tactical benefits and also build confidence for the bolder steps to come. ★

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


Marc-Antony Payne

▼ **This Boeing 777 crashed** at London's Heathrow Airport in 2008 after flying through air temperatures of minus 74 Celsius.

Flying through extreme cold

Debra Werner described efforts to develop an operational workaround to prevent recurrence of an accident that occurred in 2008 at Heathrow ["Danger in the air," March]. Extreme cold at flight altitude caused ice crystals to form in the fuel, resulting in engine power loss during approach. This ice formation process compromised the capability of a fuel-oil heat exchanger designed to limit low fuel temperatures.

Ms. Werner reviewed research into methods of measuring temperature and moisture profiles in the atmosphere. Further research will be directed at providing broad area temperature and moisture profiles that will ultimately be used by air traffic controllers to warn pilots of dangerous cold cells aloft. These results are expected to be available for operational use in a few years. Thus, a possible operational workaround may be available 12 or so years after the cited accident.

Mechanical engineers will ask: "What about the heat exchanger?" If the heat exchanger fell short of real-life operational requirements, would it not have been prudent to consider design changes to these devices, as well as changes in flight operations, to solve the problem? Heat exchanger design has been the bedrock for thermo-mechanical engineering and chemical flow processing for over a century. Absent other constraints, this would seem to be a prime candidate.

Perhaps there are design factors that make such changes impractical, things like materials limitations, aircraft weight and space limitations, or some limit in the physics of heat exchange at extreme temperatures. If such is the case, the article would have been strengthened by discussing those factors.

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CORRECTION

We incorrectly identified the contractor for NASA's Space Launch System in the April article "Reaching Europa." Boeing is the prime contractor for the SLS core stage; Aerojet Rocketdyne provides the four RS-25 engines; and Orbital ATK is building the boosters.

Sustaining complex aerospace systems

Keith Button's article in the March issue, "Wringing out the risks," is a good read and I recommend it. However, I would like to add a bit of engineering philosophy rarely discussed: Long-lived complex systems are kept viable by detecting new, emerging failure modes with sufficient lead time ahead of the needed actions.

The sustainment phase of any complex system has several unique characteristics. For instance, the baseline shifts from "design" to "war-fighter expectations," or sometimes called a "capabilities baseline." Also, schedules shift from meeting initial operational capability or other critical milestones to determining the correct schedule to mitigate emerging risks lead time from impact. There are more, but the most important to this article is the shift from a FRACAS [failure reporting, analysis, and corrective action system] program in production, to a Closed Loop Failure Analysis contract with your repair depots.

Left to nominal, repair depots must focus on efficient production and speedy throughput. Important data about how your system is changing over time gets lost. A contract between the depot and the sustaining organization directs their efforts to discover emerging failure modes never dreamed of when the FMEAs [failure modes and effects analyses] were being written. The models discussed in the article can be updated with this new information. Aggressively going after this information was one way the U.S. Air Force and its contractors kept the Minuteman 3 meeting its mission for six decades despite only a few test flights per year. My role in the intercontinental ballistic missile team before I retired was defense contractor systems engineer.

If improving sustainment for all complex systems appeals to you, join our AIAA Complex Sustainment Community of Interest on AIAA's Engage collaboration platform (engage.aiaa.org).

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AIAA's Next Era of Innovation and Exploration

It is a great honor to write this first column as the new President of AIAA. Over the next two years, I have a single overarching goal for the Institute: to reverse the long-term membership decline and get our organization growing again. The aerospace industry is healthy and growing, though it is changing dramatically with the introduction of new players and new technologies. Yet, since the start of the current century, our professional membership has declined at a consistent annual rate of about 3% per year. We cannot serve our profession if we do not adequately represent it. We must change and adapt in order to grow. Reversing this membership decline must be our first order of business.

In pursuit of this goal, there are four broad themes I plan to focus on:

- **Technical excellence.** We are the professional society for aerospace. The Institute is founded on a core of technical excellence; it is essential to our identity and our credibility.
- **Transparency.** We each *choose* to belong to AIAA; it is an organization of volunteers. Everything we do should be open and transparent to our membership.
- **Diversity.** We in aerospace undertake some of society's most noble and ambitious pursuits. We must do a better job of reflecting that to society. We must make the Institute a more welcoming home for aerospace enthusiasts regardless of gender, race, or national origin. We serve as role models and must be visibly inclusive.
- **Outreach.** We will need to reach out in many directions: to new, entrepreneurial companies that are emerging, to new technical disciplines such as information sciences and robotics, to the next generation, and to groups we do not adequately represent today, particularly women and minorities.

To do this, we will need to both celebrate the past and look to the future. 2019 will mark the 50th anniversary of the first moon landing. This was one of the most important events of the 20th century (and some would say in all of human history), and nothing better exemplifies the spirit of innovation and exploration that our profession represents. In 2019, AIAA will host the International Astronautical Congress (IAC) in Washington, D.C. I encourage each of you to participate in this event. The IAC is a starting point, but we can and must do much more in answering the question "What's Next?".

Over the next two years a topic you will hear me stress a lot is that of "paying it forward." I am thrilled to announce a perfect example of this—the largest gift in the Institute's history. In 1959, a Grumman engineer and test pilot named Roger Wolfe Kahn set up a trust with the Institute of the Aerospace Sciences (one of AIAA's precursors) as the ultimate beneficiary. The conditions of that trust—to first take care of his family, among other things, were recently satisfied and AIAA has already received $7 million from the Kahn Trust. What we do with it is up to us. I know for sure that we want to celebrate it, invest it wisely, and encourage others to emulate Kahn's generosity.

- **Celebrate.** This is an amazing act of generosity and of long-term planning. We'll use *Aerospace America*, AIAA.org, and our social media channels to tell everyone about Roger Kahn's story.
- **Invest.** We now have the obligation to use these funds wisely. Should we set up a matching fund strategy and give the combination to the AIAA Foundation? Should we endow scholarships? Fund some new commemorative prize? Underwrite some new large outreach initiative? There are a wide range of possibilities and together we can achieve great outcomes.
- **Emulate.** The Kahn story is inspiring, but it need not be unique. Our country is about to undergo the largest intergenerational transfer of wealth in history. We should build on the Kahn legacy, and encourage investment in our Institute as part of members' estate planning.

I would love to hear **your** ideas—write me at KahnTrustIdeas@aiaa.org and tell us what you think AIAA should do. We will share this with our professional staff and our Board and plan to include you in our decisions. We'll also get a conversation going on the new AIAA Engage.

Let's celebrate the past while we reach for the future. I look forward to the next two years! ★

John S. Langford
AIAA President

"WannaCry" malware sparks fears of aerospace cybersecurity gaps

BY TOM RISEN | tomr@aiaa.org

Automated industrial devices, including sensors or robotic arms in airplane factories, can damage assembly lines if infected by malware, say U.S. cybersecurity analysts. They are sounding the alarm about what they view to be a lax cybersecurity culture in the manufacturing sector that includes insufficient sharing of information about malware.

I spoke to analysts after the Seattle Times, citing an internal Boeing memo, reported that the company experienced a "WannaCry" infection that began spreading from its facility in North Charleston, South Carolina, where Boeing 787s are assembled.

A Boeing spokeswoman confirmed in a statement that there was a malware incident, and said the company "quickly applied the appropriate fix with a software patch." The statement did not identify the malware.

"It was limited to a small number of machines within our commercial airplane business," the statement reads. "There was no interruption or impact to any aircraft production. We have made appropriate notifications to authorities and there's no further follow-up requested or needed at this time."

Analysts say there are risks of more serious incidences that could stop factory assembly lines in the U.S aerospace sector. "A lot of factory machines are leased and not owned," says Jake Williams, a former U.S. National Security Agency cybersecurity analyst. Manufacturers including aerospace companies often rely on a third-party group to make security patches to update machines connected to their network and prevent them from becoming infected.

"Alternatively, a company owns a machine but they can't patch it because that would void the warranty," says Williams, now the president of Rendition Infosec cybersecurity consulting firm in Georgia. "In the manufacturing industry it is difficult to apply best practices."

Microsoft stemmed the global infection of the WannaCry malware last May by releasing a series of security patches to fix the vulnerability that the infection exploits on Windows software. Williams has no information about the Boeing incident beyond news reports, but he speculates an infected machine could have spread the malware to other machines connected to the company's internal network. Malware can flow through the internet far beyond its initial target, and Rendition has seen malware affect machines accidentally or through deliberate hacker attacks. Malware "definitely can take a plant down," including airplane factories.

A working group of engineers, established in December, has been trying to create cybersecurity standards for industrial automated machines and control systems. The group was established by the International Society of Automation, a nonprofit headquartered in North Carolina. Joe Weiss, a cybersecurity analyst and the head of this working group named ISA99, wants more software forensics data about how malware can affect industrial machines, including robot arms that are not directly connected to the internet but could be infected by connecting to other machines. Process sensors, actuators and drives that run industrial automated machines are not considered as part of a cybersecurity strategy, he says, adding "these insecure devices are critical to all commercial, industrial and defense applications."

"To IT, cybersecurity means the network, not control systems," Weiss says of devices including sensors that guide robots. "Can that network vulnerability affect the robot on the factory floor, the valve in the power plant or motor in a compressor station?"

The U.S. Department of Homeland Security's National Cybersecurity Communications and Integration Center shares information about WannaCry and other malware threats with the Aviation Information Sharing and Analysis Center, a group formed in 2014 to represent aviation industry firms.

"This partnership ensures that industry members and the government are fully aware of threats such as WannaCry and the best practices for mitigating such threats," said a statement from Aviation ISAC.

Government officials are also soul-searching about how much cybersecurity information they should share about software vulnerabilities that are in rare cases stockpiled by intelligence agencies that can make it easier for U.S. spies to break into a target's computers.

The WannaCry infection took off last May after a group of hackers called the Shadow Brokers published a Windows vulnerability online in April 2017 called EternalBlue as part of a trove of software exploits that the leakers claimed to have stolen from the NSA.

White House Homeland Security Adviser Tom Bossert said in December that North Korea was responsible for spurring the WannaCry attacks in May but indirectly acknowledged the NSA.

"The government needs to better protect its tools, and things that leak are very unfortunate," Bossert said.

Williams did not confirm if EternalBlue originated from his former employer the NSA, but he says "there is no question" the EternalBlue code was used to create WannaCry. ★

NASA to survey Galveston residents on sonic thump

BY KEITH BUTTON | buttonkeith@gmail.com

In November, residents of Galveston, Texas, should hear a beta version of the double-thump sound that NASA expects will be generated by its planned "low-boom" supersonic X-plane when it starts flying in 2022.

NASA knows that if commercial jets are to fly supersonically in U.S. skies one day, residents must find the noise tolerable. The question is how to gather enough data to define what is tolerable. So, the agency plans to simulate the sounds of the X-plane by flying F/A-18s about 40 kilometers offshore from Galveston and into a supersonic dive from 50,000 feet. The agency will try out community surveying techniques that it will apply during the flights of the Lockheed Martin-built Low-Boom Flight Demonstrator that will test noise reduction designs for commercial developers.

In the past, NASA has surveyed residents of Edwards Air Force Base, California, about jet noise and asked volunteers to sit inside a simulated home, called the Interior Effects Room, at Langley Research Center in Virginia. With the Galveston flights, NASA hopes to learn how to survey a large community that's largely unfamiliar with the noise from supersonic airplanes, says Peter Coen, project manager of NASA's Commercial Supersonic Technology Project.

The techniques need to be ready by 2022, when NASA plans to fly the X-plane over multiple communities and then survey the residents, storing the results in a database. The FAA and the International Civil Aviation Organization could then set standards for acceptable noise levels for overland commercial supersonic aircraft, which are currently banned in the U.S. and other jurisdictions.

"Right now, we're just trying to get a handle on how do you engage a community; how do you engage their elected leadership in a positive way; how do you plan a deployment for airplanes; how do you deploy acoustic sensors; how do you engage survey participants to conduct such a survey," Coen says.

NASA will survey Galveston residents through a web application, asking them what they heard and what their response was to the sound. The double-thump noise to be emitted by the low-boom demonstration aircraft, and replicated by the NASA F/A-18 research planes, sounds like a next-door neighbor closing his car door, Coen says. Because survey subjects on the ground may not even distinguish the sound from background noise, one question NASA wants to answer with its Galveston tests is whether the agency needs to text residents after a flight to prompt them to fill out a survey response, says Jonathan Rathsam, a NASA research engineer at Langley.

NASA will fly two F/A-18s — one serving mainly as a spare — out of nearby Ellington Airport. The planes re-create the low-boom noises by diving from 50,000 feet, hitting supersonic velocity briefly at 40,000 feet and leveling out at 30,000 feet. NASA plans to create one to eight sounds per test day, with about 14 test days over a three-week period. By creating the sonic booms 40 kilometers off shore, the sounds will be softened by the time they reach the ears of Galveston residents. While NASA won't notify onshore Galveston of the specific test days ahead of time, it will give a heads up to the maritime community because boats and ships below the F/A-18s will hear normal supersonic booms, akin to the sound of a clap of thunder directly overhead, Coen says. ★

NASA

▲ NASA will fly an F/A-18 research aircraft offshore from Galveston, Texas, into a supersonic dive that will mimic the thump expected from its Low-Boom Flight Demonstrator, or LBFD.

U.S. Navy determined to get sense-and-avoid onto Tritons

BY TOM RISEN | tomr@aiaa.org

The U.S. Navy will deploy its first two MQ-4C Triton unmanned surveillance aircraft by the end of 2018 without sense-and-avoid radars that would give the planes limited autonomy to avoid other aircraft, says a rear admiral who hopes that upgrade will be ready by 2021.

The planes, built by Northrop Grumman, are destined for Guam, from which they will carry maritime radars to detect ships from 55,000 feet, eventually for as long as a day at a time.

The separate sense-and-avoid radar originally designed for the Tritons "wasn't optimized for how it was going to operate," said Rear Adm. Mark Darrah, during a panel discussion in April at the Navy League's Sea, Air and Space Exposition in Maryland. So the aircraft will be sent to Guam "with the basics we require" to safely navigate international airspace aided by the Automatic Dependent Surveillance-Broadcast flight tracking network and ground radar stations, he said.

Darrah spoke about the need to improve technology for unmanned planes to sense other aircraft, and to process that information to avoid collisions.

"We've got to do some work on application of the algorithms and the processing based on the class of system we are going to provide sense-and-avoid for," said Darrah, who is program executive officer for U.S. Navy unmanned aviation and strike weapons.

"Same thing for the underwater systems," he added, noting that U.S. Navy unmanned ships being developed to monitor oceans above and beneath the waves need better technology to respond to their surroundings.

The first two Tritons will be deployed to Guam by the end of 2018 after operational tests at the Naval Air Warfare Center Weapons Division in Point Mugu, California. Additional Tritons will be deployed to Guam by 2021, the Navy said.

The Navy aims to add sense-and-avoid technology to the Tritons by 2021, specifically the Common Radar Airborne Collision Avoidance System developed by RDRTec of Texas and the Airborne Collision Avoidance System Xu, or ACAS Xu, developed for unmanned aircraft by MIT's Lincoln Lab.

Controllers on the ground will attend to the aircraft, but the radar upgrade could add limited autonomy for sensing other aircraft while meeting U.N. International Civil Aviation Organization safety rules, Darrah says.

▲ **The U.S. Navy plans to base its first MQ-4C Triton** surveillance aircraft in Guam.

U.S. Navy

"Sense-and-avoid is an unmanned challenge we have to deal with, whether it is commercial or military," Darrah says. "The radar technology isn't the hard part, it's the processing of the information to decide what to do with it."

Consumer drones can be given sense-and-avoid programming to detect their surroundings and fly autonomously through obstacle courses, but Darrah says that is simpler for smaller drones in a controlled environment without high-altitude winds that the much larger Triton would have to navigate.

"It's got to look at how fast it is flying, its altitude, what are other conditions around it, is it experiencing turbulence, can it manage a turn and not stall the airplane," Darrah says. "It's got to go through all that calculation in a time frame that makes sense."

The Navy said in a statement that technical challenges led to cost increases and schedule delays during development of the original Airborne Sense and Avoid three-panel radar that was built to fit in the nose cone of the Triton.

"The technical challenges included issues in designing and producing a system that could meet technical requirements within the available size, weight, power and cooling parameters," the Navy said. "The Navy resumed work with the sense-and-avoid radar in 2015. Triton will have broader access to international airspace with the sense-and-avoid radar." ★

U.S. Army

Rotorcraft modernizer

More online aerospace america. aiaa.org

Brig. Gen. Thomas Todd III is leading the U.S. Army's Program Executive Office-Aviation to a potential revolution in rotorcraft technology and toward retirement of some of the workhorse helos from the wars in Iraq and Afghanistan. The Army is considering whether to embark on its first clean-sheet helicopter design since the 1980s, and Todd's engineers at Redstone Arsenal in Alabama are in the midst of analyzing the alternatives: the Valor 280 demonstrator, a tilt-rotor rotorcraft from Bell that started flying in 2017, and Boeing-Sikorsky's coaxial-rotor demonstrator, the SB-1 Defiant, slated to fly this year. Todd also is in the process of retiring the TH-67 Creek training helicopters and also the OH-58 Kiowa Warrior armed scouts that served as the Army's armed reconnaissance workhorse in Iraq and Afghanistan. I spoke by phone to Todd, who was in his office at Redstone Arsenal in Huntsville, Alabama.

— *Keith Button*

BRIG. GEN. THOMAS TODD III

POSITIONS: Program Executive Officer, Program Executive Office-Aviation, since January 2017; previously U.S. Army Research, Development and Engineering Command deputy commanding general and, concurrently, senior commander of the Natick Soldier Systems research complex in Massachusetts for two years.

NOTABLE: Todd led deployments into Iraq and Afghanistan to equip and train combat aviation brigades. Last year, he was deployed to Honduras as the chief contracting officer for Hurricane Mitch relief efforts in Central America. He is also a UH-60 Black Hawk helicopter test pilot, and is rated to pilot UH-1 "Huey" utility helicopters; OH-58 Kiowa Warrior armed scouts; the rugged UH-60M version of the Black Hawks; and CH-47F Chinook transport helicopters. Was deputy commanding general of the U.S. Army Research, Development and Engineering Command, and senior commander of the Army's Natick Soldier Systems Center research complex in Massachusetts.

AGE: 50

RESIDES: Owens Cross Roads, Alabama

EDUCATION: Bachelor of Science in business administration from The Citadel; graduate of the Army Aviation Officer Advanced Course, and Command and General Staff Officer Course; Master of Science in contract management from the Florida Institute of Technology, and Master of Science in strategic studies from the U.S. Air War College.

IN HIS WORDS

Power of software
The number one change I have seen is the proliferation of ones and zeros throughout all our hardware. If you think about it, years ago even when we started with the Black Hawk, and the Apache, and the Chinook, [they] largely didn't have a whole lot of software. Software brings with it a lot of attributes, but it also brings with it some instability in that you have to maintain it. Going forward, the challenges for our soldiers really will be for us to take advantage of the software attributes that allow us to be agile. We need to bring new capabilities into those aircraft, both for the aircraft itself as well as mission equipment packages. And at the same time we need to keep it stable, maintain it, and keep it at the high qualities and performance that we expect.

Engine performance
Our biggest trends outside of the software arena are technologies that allow for new types of engine performance, whether it be composites or new materials. And then, concepts for vertical lift. The demonstrators that are currently flying today, whether it be a tilt-rotor variant, some sort of a unique X-wing, or what I would consider to be a compound coaxial design — they're showing promise today that quite frankly we were unable to achieve before software and fly-by-wire entered the equation. Engine performance has been specific to the current fleet and things that we can do, but there are significant changes in concepts of vertical lift, that are going to help us cross the thresholds of speed and range that we've never been able to cross before.

Supervised autonomy
In the Army, we operate very close to the ground, and what the fly-by-wire capability allows us to do is get us to a flight handling quality that reduces pilot workload; allows us to operate in environments that we perhaps would not have been able to operate in — i.e., obscure environments, whether it be brown out or weather. At the same time, [we can] potentially introduce what we consider in Army Aviation to be supervised autonomy, or supervised autonomous flight. Some people call it optionally manned flight; optionally piloted.

We have demonstrated that. We have several fly-by-wire Black Hawks that — through a cooperative research and development effort between our labs as well as Sikorsky — demonstrated an optionally piloted Black Hawk using that fly-by-wire technology flown from a common controller on the ground. And so, we know it's possible. We know there's going to be areas in the future battlefield that require us to deploy assets for critical resupply of materials. Food and water, or ammunition, and deploying an optionally piloted or autonomous vehicle into that environment will be something that we would do that we perhaps would not do with people on board. So fly-by-wire is really paramount, and flight handling characteristics achieved by that fly-by-wire are going to be paramount in all those different environments in the future.

I believe we will take a pretty big leap in capability in performance of these airframes over the next 10 to 15 years.

Future rotorcraft
The workforce here is committed to bringing the future of vertical lift to the U.S. Army as well as the Department of Defense. We are really at a crossroads. We have tried before concepts that take us where really the physics don't allow us to go in air speed, and reach, and payloads. But the promising technology demonstrations that we have ongoing now, as well as what we've been able to do to modernize the current fleet really bodes well for the future of vertical lift where we, I believe, will take a pretty big leap in capability in performance of these airframes over the next 10 to 15 years.

Analysis of alternatives
Currently inside our organization, we have the [program manager] for future vertical lift, and he is supporting the Army analysis of alternatives, which is ongoing this year and is expected to conclude early next fiscal year. There are two demonstrators that will be flying, and our science and technology partners are really leading that charge. [One of] those demonstrators, one the Valor 280, has already flown and the Boeing-Sikorsky Defiant should fly over the next year. And those are the two flyable demonstrators that they plan to have flying. Those will inform that Army analysis of alternatives this year, and affect the path forward that we move out on next year.

Existing aircraft as solution
Now to be clear, the analysis of alternatives is to help the Army make a decision on [whether] we pursue a new clean-sheet program like that, based off what we've learned, or is there something that already exists that wouldn't be considered a developmental program that we could pursue to achieve, really, what is the goal of going farther, faster, and with more than ever before.

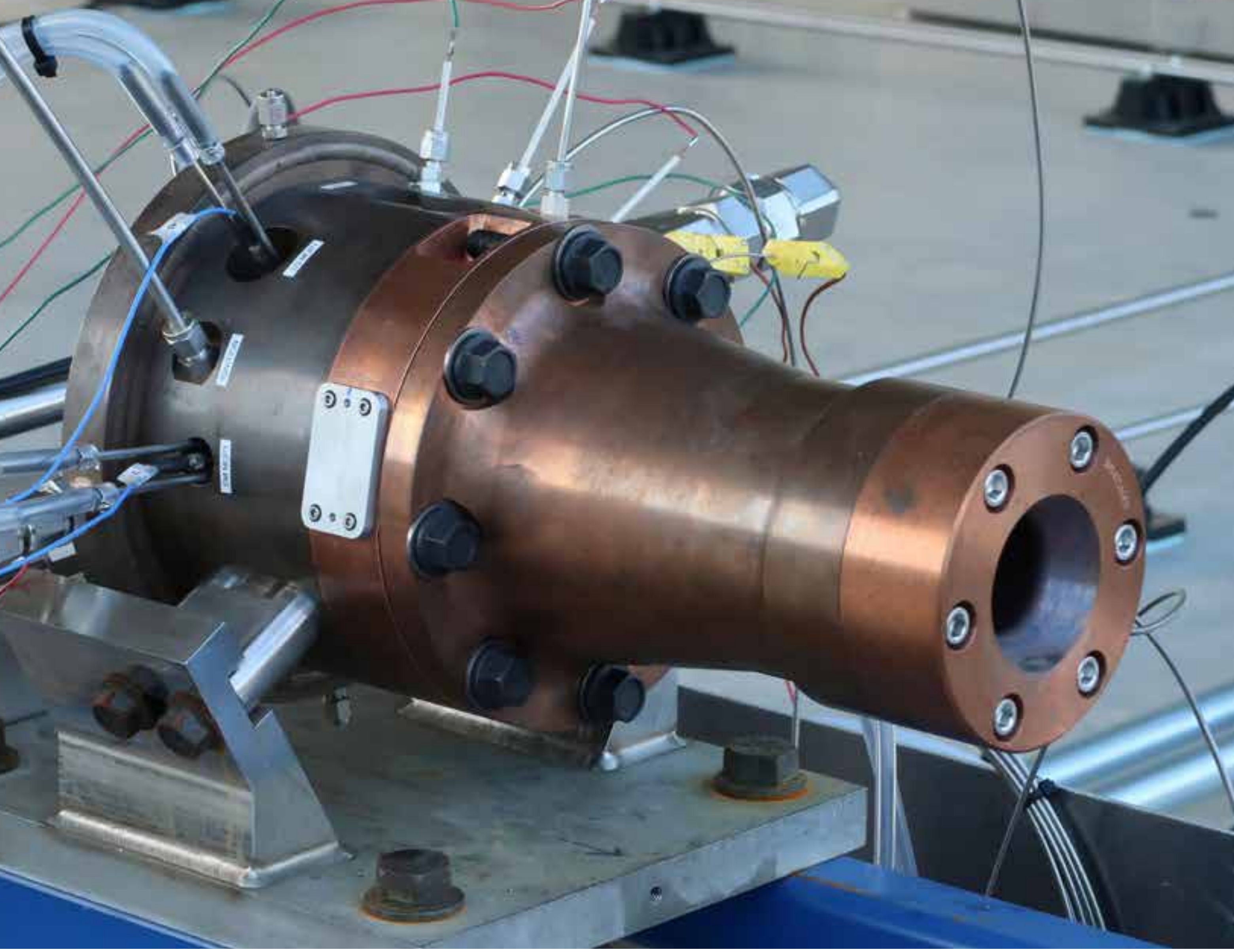
[Also], because of the scale of the Army and the number of platforms that we require, sometimes double and triple what other services require in vertical lift, we always have to take into account unit cost and cost per flight hour. That assessment will also take into account affordability of any approach.

How they perform obviously would go into what kind of proposal they would be able to put forward. But we would anticipate a full and open competition should we be asked to move forward. They would be able to compete, and certainly they would have made advancements, but we would expect the full and open competition to really select the best design. There's no down-select planned out of the demonstration. ★

INCREASING ENGINE EFFICIENCY

BY KEITH BUTTON | buttonkeith@gmail.com

Today's turbine engines perform well in their jobs of generating electricity in power plants or thrust if the application is a jet engine. There's always room for improvement in fuel efficiency. What if the design of the combustor could be redrawn to rotate gases and produce a succession of highly energetic fuel-air detonations? Experiments show this would be more efficient. Keith Button spoke to researchers who are among those vying to lead the way in the design and testing of rotating detonation engines.



A turbine engine must generate a uniform flow of combustion gases to spin its blades without excessive wear or risk of damage. A conventional turbine engine avoids damaging spikes in temperature and pressure by allowing the volume of gas to expand, which encourages even deflagration, the term for the rapid burning of the fuel-air mixture as it's sprayed or injected into the combustor. The resulting stream of combustion gases rushes through the engine, spinning turbine blades before it exits.

Aerojet Rocketdyne's Advanced Programs-Rocket Shop in Alabama is working on a radically different combustor design, one that would release energy in a rapid, continuous succession of detonations set off by shockwaves rotating inside a cylindrical combustor. Less fuel would be burned to turn the blades at a given speed, but the engineers must avoid subjecting the turbine blades to fluctuations in temperature and pressure that could damage them or wear them out too soon.

Aerojet Rocketdyne has until June 2019 to demonstrate on university test rigs that its ideas for a rotating detonation combustor can meet that challenge. If all goes as planned, researchers will demonstrate pressure gains and characterize the flow upstream, which would be critical steps toward developing a rotating detonation combustor that could be slid into a power plant turbine. That feat could, in turn, point to a version for jet engines someday.

The company is developing components of the combustor under a $6.8 million, three-year contract with the Energy Department's National Energy Technology Laboratory. The team is among others in the U.S., plus China, France, Japan, Poland and Russia that are experimenting with designs for combustors that would turn conventional engine designs into rotating detonation engines.

Conservatively speaking, a rotating detonation combustor, or RDC, should reduce specific fuel consumption by about 5 percent compared to a conventional engine. This measure of fuel efficiency is calculated by dividing fuel consumption by power

▲ **A subscale rotating detonation engine** was tested at the Southwest Research Institute in San Antonio, Texas. The 10-centimeter-diameter rotating detonation combustor is the gray portion of the machine. The exhaust comes out of the diffuser on the right.
Aerojet Rocketdyne

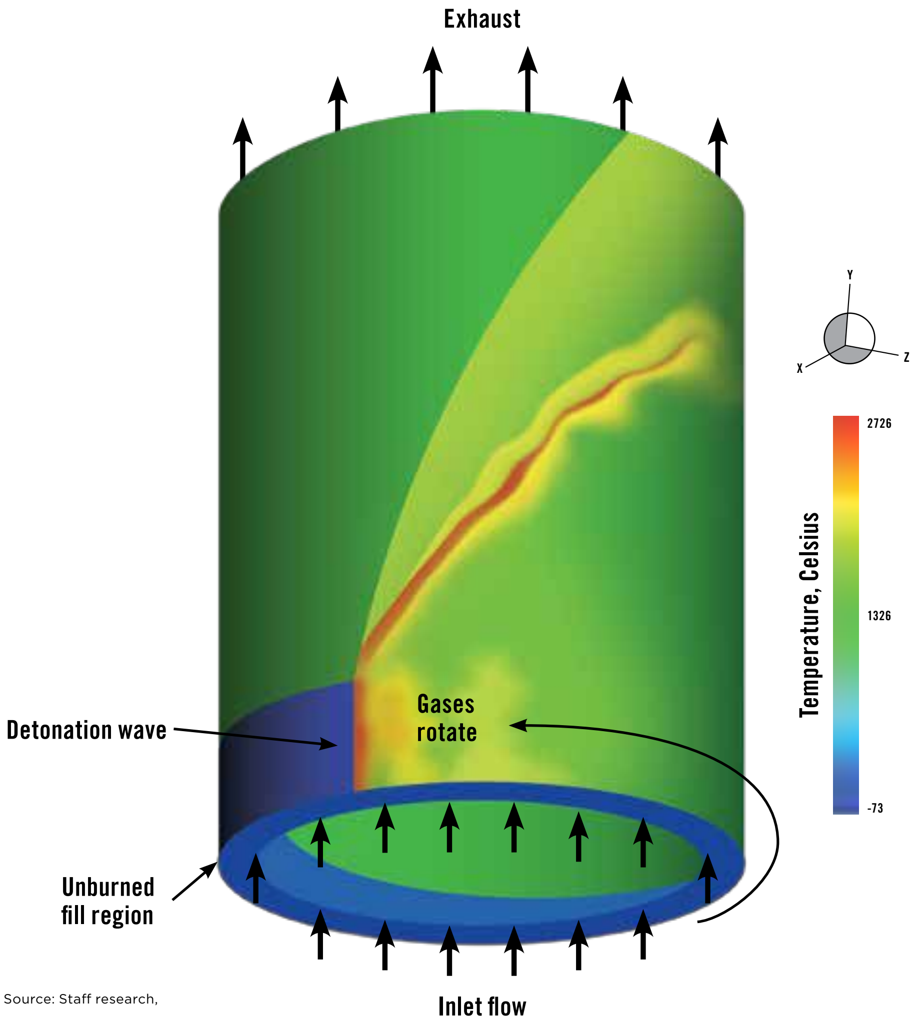
output. A rotating detonation engine generates more power, which drives down specific fuel consumption. A reduction on the order of 5 percent would be a breakthrough, given that designers of conventional engines "try to eke out fractions of a percent," says Scott Claflin, director of advanced concepts at the Rocket Shop, Aerojet Rocketdyne's innovation organization.

The key advantage of detonation combustion is that it generates pressure gain in the system, compared to the pressure loss produced by deflagration combustion. RDC designers aim to capture as much of that gain as possible, so that more energy is wrung out of a given amount of fuel, Claflin says.

Detonation vs. deflagration

Detonation combustion needs to occur in a space where its volume remains constant, which is why the design is cylindrical; in deflagration combustion, the volume of the combustion has room to expand. The knock in a poorly tuned car engine is an example of deflagration turning to detonation. In an RDC, the combustion starts out as deflagration but quickly turns to detonation. There are variations, but in a baseline design, the compressed air and fuel mixture enters one end and collides with a rotating shockwave produced by the previous detonation. The fuel-air mixture starts to deflagrate but then quickly detonates, producing shockwaves that propagate in opposite directions. These waves travel around the inside wall of the cylinder at 2,000 meters per second, meeting each other from opposite directions and bouncing off each other to reverse direction. Within microseconds, they establish a rotating shockwave moving in one direction that circles the chamber

Unconventional combustor



Source: Staff research, Aerojet Rocketdyne

A rotating detonation engine operates via a continuous detonation wave that propagates around the inside of a cylindrical combustor. Air and natural gas propellant (blue) are introduced continuously through the inlet and react across the detonation wave that is moving perpendicular to the incoming propellant. High-temperature, high-pressure products behind the detonation wave expand and exhaust out (top) to drive a turbine or generate thrust. Once the process begins, it self-sustains as long as the inlet propellant is flowing.

every 0.1 millisecond. The rotating wave slams into the next burst of air-and-fuel mixture entering the combustor, causing it to detonate, and the process repeats itself. There are variations to this baseline approach that involve multiple shockwaves traveling in the same or opposite directions.

Detonation combustion burns a given unit of fuel tens of thousands of times faster than deflagration. This creates pressure spikes with 10 to 1 fluctuations. Deflagration, by contrast, produces a smooth flow field into the turbine with a fraction of a percent variation in pressure and mass flow rate. Conventional combustors "have been designed throughout history to absolutely minimize any pressure perturbations in those devices," Claflin says.

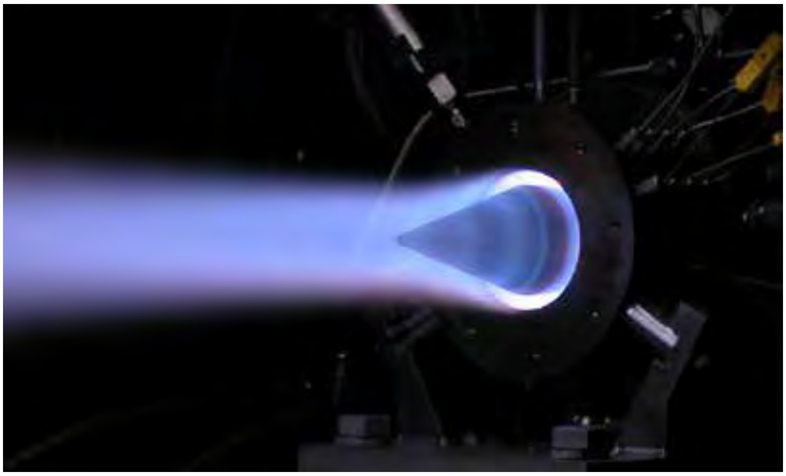
Introducing unfiltered detonation combustion inside a conventional gas turbine "would be a disaster" largely because of the beating that the engine components would take, says Carson Slabaugh, an assistant professor who leads Purdue University's contributions to the Aerojet project. "You would want to make that flow as steady and uniform, as homogeneous as possible, to try to improve the life of your turbine."

Unsteady pressure, temperature and airflow would make thermal management very difficult, especially for the hot sections of the engine. For RDCs to succeed, engineers need to make them produce airflows that are just as steady as conventional combustors. At the same time, the engineers need to make sure that the damping or smoothing of the airflows doesn't take away their advantage: the pressure gain.

Aerojet Rocketdyne's engineers designed a device called a diffuser that's shaped to smooth out the combustor's airflows as they enter the turbine, Claflin says. "The specifics of how you design the geometry for a rotating detonation engine, no one has ever done that before. So we're learning for the first time how to design an efficient diffuser for a very unsteady rotating detonation engine."

Claflin says how the diffuser works is classified, related to Aerojet Rocketdyne's ongoing work with the Department of Defense. But, he says, the diffuser's design relies on geometry, not moving parts, to smooth out the pressure and temperature variations.

Aerojet Rocketdyne engineers initially drew lessons from ramjet engines, in which incoming air rams into a structure such as a cone to compress it and slow it to subsonic speeds for combustion, and also from supersonic combustion ramjets or scramjets, in which the air stays at supersonic speeds. These designs require isolators, short ducts between the inlets and combustors that prevent air from backing up and interfering with the incoming air. Researchers tested their diffuser ideas first as CFD (computational fluid dynamics) models, then as scaled-down physical models on test rigs at the University of Alabama, the University of Michigan, Purdue University and Southwest Research Institute. The researchers collected data on the velocities, pressures, temperatures, and chemical species in the flow fields entering and exiting the RDCs.



Aerojet Rocketdyne

▲ **Exhaust flows from** a rotating detonation engine during testing.

"If you just do a CFD analysis, you don't know if it's predicting reality or not until you have something to compare it against. We're coming up with the empirical data base that the CFD analysis can be compared against," Claflin explains.

Currently, the Aerojet Rocketdyne engineers are on their third iteration of their diffuser. They want to see how it performs as they scale it up, Claflin says. They plan to test a 36-centimeter RDC with a diffuser in May at Purdue. By the time the project wraps up in 2019, they plan to test 50 percent scale model RDCs with diffusers that are about 50 centimeters in diameter.

The engineers are also concerned about how shockwaves in their rotating detonation combustor might interact with the compressor, blades upstream of the combustor that compress incoming air before combustion. They don't want to allow pressure pulses from the detonations in the combustor to move upstream into the compressor, which could disturb the compressor flow or even reverse the direction of the airflow, says research engineer Donald Ferguson of the National Energy Technology Lab in Morgantown, West Virginia.

"You can imagine if you're generating even a controlled detonation inside that combustor, that the resultant pressure pulse that comes from that wants to go in all directions," Ferguson says. "We want to contain that with a nonmechanical valve of sorts."

As with the diffuser, the engineers are developing a nonmechanical solution that relies on geometry. This concept is considered critical military technology so details are not releasable, Claflin says.

Once the current project is completed, Aerojet Rocketdyne's next step would be to integrate a full-scale RDC into an operational turbine engine, Ferguson says. ★

GRADING THE MQ-25

BY JAN TEGLER | wingsorb@aol.com

Three contractor teams are competing to build the U.S. Navy's proposed MQ-25 Stingray drones whose main role will be to fly from aircraft carriers to refuel piloted warplanes, especially stealthy F-35Cs once they are deployed. Is this the best strategy for empowering the Navy to penetrate enemy airspace when that's necessary? Jan Tegler dug into that question by interviewing current and former officials, including the Pentagon manager who decided on the strategy.

Two Lockheed Martin MQ-25 prototypes on the flight deck of an aircraft carrier in an illustration.

Lockheed Martin

"When is the MQ-25 going to turn into a viable ISR strike asset that can be used in actual combat? Is it 2030, 2040, maybe 2060? If you don't invest in overcoming hard challenges up front, you're going to be late."

— Retired U.S. Air Force Lt. Gen. David Deptula

In the decade after 2005, a succession of U.S. unmanned X-planes demonstrated some of the key tasks that carrier-based U.S. Navy F/A-18s do today and that stealthy F-35C warplanes will do in the future. Test drones made arrested landings on an aircraft carrier, coordinated a simulated pre-emptive strike against enemy air defenses, and delivered bombs onto test targets in the desert.

Those who witnessed that pioneering decade of X-plane flights probably could not have predicted that in late 2015 the Defense Department would choose unarmed drones with belly pods as the first unmanned aircraft destined for its aircraft carriers. These aircraft would ferry jet fuel to conventionally piloted F/A-18s and F-35Cs to extend their ranges. It's an unglamorous role but one that the Navy says is crucial for projecting power hundreds of kilometers from its aircraft carriers.

Late this year, the Navy plans to announce its selection of a contractor to build the drones, to be called MQ-25 Stingrays. The Navy will act as the lead systems integrator to ensure that those airframes operate correctly with software and equipment that the Navy will purchase separately for "air vehicle operators" who control the aircraft from stations aboard carriers. The primary mission will be aerial refueling plus some modest intelligence, surveillance and reconnaissance capabilities, given that the M in MQ-25 refers to multimission. At stake for the competitors is a contract that could grow into an acquisition of 72 Stingrays under a $5 billion "cost ceiling," as the Navy calls it. The White House has requested $719 million for the program in its 2019 budget proposal, and the Navy anticipates purchasing the first four aircraft in 2023 and starting operations from carriers in 2026.

I spoke to program officials, retired military officers and a former deputy defense secretary to explore whether the MQ-25 is the best strategy for achieving the ability to reach deep into enemy air defenses from carriers. Before the MQ-25, the Navy was aiming for a stealthy surveillance and combat plane under a program called UCLASS, short for Unmanned Carrier-Launched Airborne Surveillance and Strike.

As for the contenders, Boeing's prototype, which it calls T-1, draws on previous experimental aircraft and the design it pitched for UCLASS. General Atomics Aeronautical Systems Inc. (GA-ASI), meanwhile, is bidding a variant of its Sea Avenger carrier-jet concept that it proposed under UCLASS. In an unusual twist, the company announced in February that it has partnered with a business unit of one of its competitors, Boeing Autonomous Systems. The Boeing and GA-ASI designs have versions of V tails. Lockheed Martin, in contrast, is proposing a flying wing derived from its stealthy Sea Ghost concept that it previously pitched to the Navy.

If all goes as planned, one of these designs will be chosen to take aim at a problem shared by the Navy's carrier-based F/A-18 Hornets, Super Hornets and EA-18G Growlers, the variants of the Super Hornet equipped for tactical jamming. Today, for some missions, pilots must take on gas in flight from U.S. Air Force tanker aircraft or other carrier-based

DECK MANEUVERING

The U.S. Navy wants carrier-deck personnel to guide MQ-25s on the deck with the same gestures and signals that they give to pilots of conventional planes. Boeing, General Atomics Aeronautical Systems Inc. (GA-ASI), and Lockheed Martin each have a strategy to meet that requirement.

Boeing did not describe its approach to us, but said it has demonstrated it: "We marked the outline and key features of the carrier flight deck on the airfield (in St. Louis) and successfully conducted a series of daytime and nighttime air vehicle maneuvers demonstrating our ability to safely operate the vehicle on the [carrier] flight deck."

GA-ASI's program director Chuck Wright explained his company's approach like this: "Flight deck directors make their normal gestures with special wands that interpret their motions to give the appropriate command. The command is then sent to the air vehicle, which executes it — taxi forward or spread the wings — whatever it was." LED lights on the MQ-25 empower it to "talk back" to the controller by changing colors to acknowledge commands, GA-ASI added. "Think Wii for aircraft control," a reference to the Nintendo interactive video game.

Lockheed Martin did not describe its approach.

Competitors draw on the past

Three companies are vying to supply the U.S. Navy with a $5 billion fleet of unmanned jets that would fly from aircraft carriers to refuel conventionally piloted F/A-18s and F-35Cs.

BOEING

Boeing's prototype, shown at the company's facility at St. Louis Lambert International Airport, has conducted a series of deck-maneuvering tests, but has yet to fly. The aircraft is notable for the placement of its engine inlet on top of the fuselage. The aircraft looks similar to an illustration prepared by Boeing for the Navy's canceled UCLASS program, short for Unmanned Carrier-Launched Airborne Surveillance and Strike. The jet has chines, or creases, on each side of the fuselage for scattering radar. Boeing is unique in that it has built its design.

Engine: Rolls-Royce AE 3007 (like those on RQ-4 Global Hawk and MQ-4C Triton)

GENERAL ATOMICS AERONAUTICAL SYSTEMS

GA-ASI's concept, shown in a photo illustration, is derived from the two designs: The Predator C Avenger that the company has demonstrated in flight for the U.S. Air Force as a jet version of the turboprop-driven Predators, and Sea Avenger, a design pitched to the Navy under the canceled UCLASS program. The concept is notable for its V tail consisting of ruddervators, each combining the side-to-side force (yaw) of a rudder with the up-and-down force (pitch) of an elevator. The company does not plan to build a full-scale prototype.

Engine: Pratt and Whitney PW815 (like those on some Gulfstream jets)

LOCKHEED MARTIN

Lockheed Martin's design, depicted refueling an F-35C in this photo illustration, is notable for its lack of a tail. The flying-wing design was derived from the Sea Ghost concept pitched to the Navy under UCLASS, but with simplifications after the Navy removed stealth requirements. "By relaxing some of the stealth design requirements that were driving that platform, we could come up with a configuration that had the aerodynamic efficiency and structural efficiency we wanted," says John Vinson, the Lockheed Martin MQ-25 program manager. Lockheed Martin has not yet built the plane.

Engine: General Electric F404 (like those on F/A-18s)

Sources: Aerospace America research, Boeing, GA-ASI and Lockheed Martin

F/A-18s configured to offload fuel from external tanks under their wings and fuselages. The time that F/A-18 pilots spend tanking diverts them from their primary strike-fighter mission while putting extra wear on the Hornet fleet.

One question on the minds of analysts and retired officers is whether a better requirement would have been to make the MQ-25 a deep-strike aircraft. The X-planes that the Air Force, DARPA and Navy worked on put a premium on radar stealth for penetrating enemy air defenses, but for the MQ-25, the Navy moved away from stealth as a requirement, given that plans call for refueling stealthy F-35Cs. Some elements of the competing designs look stealthy because of their heritage to the Navy's previous stealth requirement.

In the view of Jerry Hendrix, a senior fellow at the Center for a New American Security think tank in Washington, D.C., the MQ-25 fails to meet naval aviation's most glaring shortcoming: its lack of a long-range strike aircraft that can penetrate sophisticated defenses.

"The Navy's making their brand-new, $13 billion Ford-class aircraft carriers irrelevant. If you don't have a carrier air wing that can hit the enemy, then why do we need a carrier?"

The change in requirement may have caused one of the leading contenders for the MQ-25 contract, Northrop Grumman, to drop out last October. Observers suspect that Northrop Grumman, having already designed a UCLASS contender, was not willing to spend money on a "dumbed down" design, as one person put it. CEO Wes Bush discussed the decision in an earnings call that month: "When we're looking at one of these opportunities, let me be clear, our objective is not just to win," he said. "Winning is great, it feels good on the day of an announcement, but if you can't really execute on it and deliver on it to your customer and your shareholders, then you've done the wrong thing." A decade ago, Northrop Grumman led construction of two X-47Bs under what was known as the Unmanned Combat Air System Demonstration program or UCAS-D. In 2013, an X-47B achieved a first when it was launched from the carrier USS George H.W. Bush and returned for an arrested landing on its deck. Another unmanned first came in 2015, when an X-47B was refueled in flight by a conventionally piloted Omega K-707 tanker plane.

Some U.S. lawmakers also have taken issue with the MQ-25's scaled back role. Last July, the House Armed Services Committee, in a report accompanying the 2018 National Defense Authorization Act, applauded the proposed refueling capability but complained that the "documentation sent to industry did not include precision strike capability as a requirement."

Former Marine F/A-18 Hornet pilot Lt. Col. Dave Berke, who also flew F-22 Raptors with the Air Force and commanded the first operational F-35B training squadron, believes the MQ-25 should do more than tanking plus a bit of intelligence, surveillance and reconnaissance.

"You're building a platform for a low-threat environment that can do aerial refueling and it has some electro-optical capability," he said, using the ISR term for a camera. "But shouldn't we build a carrier-based UAV that meets as many demands as possible and has the ability to be relevant in multiple environments? That's a better investment."

Retired U.S. Air Force Lt. Gen. David Deptula, dean of the Mitchell Institute for Aerospace Studies, is also skeptical.

"They simply won't be able to operate in the kind of denied airspace that significant adversaries will be able to construct," he says.

Is there a method to the Pentagon's madness?

Former U.S. Deputy Defense Secretary Robert O. Work told me he chose to make the Navy's first unmanned carrier aircraft an aerial refueling drone in late 2015 after consultation with the Navy.

The buy of F-35Cs would be accelerated to give the Navy its stealth, and a fleet of tanking drones would be built to extend their range and the range of the F/A-18s, too.

"We would go with an unmanned system that we could afford," Work says.

Organic tanking

The Navy maintains that it will be able to conduct long-range strikes against sophisticated adversaries with a combination of stealthy F-35Cs — scheduled for deployment on carriers in 2021 — and F/A-18 Super Hornets.

The key would be what the Navy calls organic tanking, the term organic referring to equipment that a service branch owns and operates instead of relying on another service branch. The Navy says the MQ-25 is a better option for organic tanking than continuing to divert some of its F/A-18s to that role or reactivating some of the now-retired S-3 Vikings, which once provided organic tanking. Right now, the Navy must either arrange Air Force tanking, which is not always possible, or sling refueling pods under the wings and fuselages of some of the F/A-18s.

Growth plans?

Another question is whether the MQ-25, with its focused missions, can serve as a springboard to more complex missions by future unmanned aircraft.

Loren Thompson, CEO of the Lexington Institute think tank, sees a crew training aspect to the MQ-25.

"There's intrinsic danger in having people and manned aircraft operating in proximity to unmanned aircraft on deck. The Navy has to get comfortable

AERIAL REFUELING

MQ-25s will deliver fuel just like Super Hornets configured for tanking do: By carrying a 1,250-liter "buddy store" pod. A hose reel, tipped with a basket, called a drogue, would be deployed from an MQ-25's buddy store to a receiving F/A-18 Hornet, Super Hornet or Growler, a version equipped for tactical jamming. The receiving plane's nose-mounted probe is inserted into the drogue to take on fuel.

HOW THE U.S. NAVY'S MQ-25 DRONE WAS BORN

Former U.S. Deputy Defense Secretary Robert O. Work explains his 2015 decision to go with a tanker aircraft rather than a stealthy, strike plane


U.S. Defense Department

▲ **Robert O. Work** was U.S. deputy secretary of defense when he chose the MQ-25 as the Navy's next aviation acquisition.

It was late 2015, and U.S. defense planners were still going around and around about the future of unmanned naval aviation, as they had been for years.

Robert O. Work, at the time the U.S. deputy secretary of defense and a former undersecretary of the Navy, realized that the deliberations needed to be brought to a close. In coordination with the Navy, he made the decision to transform the service's Unmanned Carrier Launched Airborne Surveillance and Strike, or UCLASS, program into an initiative to build a fleet of unmanned planes to deliver fuel to conventionally piloted planes, especially F/A-18s and F-35Cs, the carrier variant of the stealth fighters.

I interviewed Work by phone at his office at the Center for a New American Security, the Washington, D.C., think tank where he now works.

He explained that his decision followed six years of debate inside the Pentagon and the Navy, with input from the Obama administration, about what form the Navy's first carrier-based unmanned plane should take.

"There were three competing schools of thought," he said.

One school advocated for a "very expensive" high-end, long-range strike aircraft capable of penetrating sophisticated defenses with a complementary reconnaissance capability.

A second school wanted a less stealthy plane with even longer range to "prosecute the terrorism fight around the world" in pursuit of "high-value targets." That was the view held by the Obama White House.

The third school wanted a plane that would offer more "situational awareness" around the carrier without being integrated into carrier operations with manned aircraft. According to Work, this was the Navy's view.

With the arguments dragging on, Work stepped in.

"I said, 'OK, what do we really need?'"

Members of the Joint Chiefs of Staff, Navy and Pentagon officials weighed in with the same answer: "stealth."

"Then I asked: 'If we started a program for a high-end stealthy unmanned penetrator that at least matched the F-35C in its stealth capabilities, how fast could we do that?"

Work said the officials responded that it would be slower than accelerating the F-35C buy.

So he decided to accelerate the buy of the F-35C and also explore Boeing's proposed Advanced Super Hornet, whose conformal fuel tanks "would extend its range and allow it to operate with the F-35C."

This way, "we would go with an unmanned system that we could afford," Work said. Tankers "would be a lot less expensive" than a "high-end penetrator," and they were "vitally needed to provide tanking for the air wing, freeing up the F/A-18s."

As for the long term, by integrating unmanned aircraft into carrier air wing operations, "we would be able to move to an unmanned future when and if the time was right and the money was there."

Work, who co-authored a 2007 report for the Center for Strategic and Budgetary Assessments in favor of unmanned combat aircraft, says he agrees that having a high-end unmanned plane capable of strike "would be good," but "I'm still looking at the budgets. I don't know how another program fits in."

He's also aware of his critics.

"Some said, 'This is the wrong thing to do. We ought to have a high-end penetrator.' To which I would say, 'That would be great if we had any money to do so.' They would say, 'You ought to cancel the F-35C and have an unmanned system.'"

"I'd tell them, 'The Navy has said they have to get stealth on deck as quickly as possible to be competitive. What is the fastest way to get stealth on deck? The answer is, the F-35C.'"

"We can afford this [the MQ-25]. We can get it out there relatively quickly and it will have an important campaign effect."

Work does have one concern about MQ-25.

"I was surprised that the IOC [initial operating capability] has been announced as 2026. I would hope we can do better," he says.

— Jan Tegler


U.S. Navy

with this. Over time, if MQ-25 works out, you can expect additional missions will gradually appear for unmanned aircraft."

Work makes a similar point. Integrating MQ-25 into carrier operations soon, he says, means the Navy "would be able to move to an unmanned future when and if the time was right and the money was there."

As for stealth, the Navy made clear two years ago that contractors should not try to reach for it with the MQ-25, telling Lockheed Martin, "Just to be clear, no credit will be given for the ability to evolve to a stealthy survivable design," says John Vinson who attended the meeting in his then-role as a Skunk Works deputy.

That clarification was needed because of the work Lockheed Martin and the other MQ-25 competitors had done toward stealthy unmanned aircraft under the X-plane programs and later UCLASS.

MQ-25's heritage can be traced to the 2003 Joint Unmanned Combat Air System program, a combined Navy and Air Force effort to field a stealthy unmanned combat air vehicle. Contractors achieved multiple breakthroughs, including a 2005 "graduation combat demonstration" over the California desert in which two Boeing X-45As simulated a coordinated strike against radars and missile launchers.

That effort was canceled following the Pentagon's 2006 Quadrennial Defense Review and relaunched as the Navy-only UCAS-D, the program that produced the stealthy, long-range Northrop Grumman X-47Bs. Lockheed Martin designed and built the aerodynamic edges, inlet lips and control surfaces, and arresting hooks for the X-47Bs.

Another twist was ahead. In 2011, the Navy transformed UCAS-D to the UCLASS program. Intended to produce a long-endurance drone with advanced sensors and a light strike capability, this program was also canceled, recast following a 2015 Defense Department review as the Carrier Based Aerial Refueling system — the program now referred to as MQ-25.

As for the oft-whispered conspiracy theory that an "F/A-18 mafia" is secretly determined to keep unmanned combat planes off the decks of ships, I could find no evidence for it.

Thompson says it's not unusual for conspiracy theories to "hover nearby" when a weighty decision about an unmanned plane is made. In his view, the MQ-25 is so urgently needed that "it kind of doesn't matter if MQ-25 happens to match up with the narrow interest of some communities."

Avoiding overreach

Lockheed Martin's Vinson says he "doesn't see strong technological challenges" in designing the MQ-25.

▲ **The U.S. Navy wants unmanned aircraft** to launch and return to an aircraft carrier at sea.

"The refueling mission does introduce issues for how we operate safely in the vicinity of manned aircraft," he notes. "But operating as a tanker, most of the responsibility is on the pilot approaching the tanker to take fuel."

He sees the operational link between the MQ-25 and the F-35Cs, which Lockheed Martin builds, as an advantage. "If anyone's going to do an accelerated capability and provide an asset complementary to the F-35C, we think it needs to be us," he says.

Vinson says Lockheed Martin focused the flying-wing MQ-25 concept it revealed in late March on the Stingray's primary mission of aerial refueling, giving it the capability and capacity to fuel Navy fighters a long way from a carrier.

Even in the refueling role, a question about sufficiency arises. The Navy says the plane must be capable of offloading 14,000 pounds [6,350 kilograms] of jet fuel 500 miles [805 kilometers] from a carrier.

Hendrix notes that while 14,000 pounds of fuel may be enough to refuel two Super Hornets, it's not sufficient for two F-35Cs. Vinson notes that 14,000 pounds is the program's "threshold requirement," and says Stingray's "objective requirement" is higher. "We're going for the objective fuel requirement. Our mission studies show we can refuel two F-35Cs."

Lockheed addressed the Stingray's secondary mission with "the ISR capability to provide an overnight watch over the carrier," Vinson says, adding, "we also get 12 hours of endurance."

The company's biggest concern specific to the tanking mission is that its Stingray be able to interrupt or break off an aerial refueling evolution safely if a problem arises.

"We have to have a way to communicate clearly to the pilot taking fuel and allow him to operate his aircraft without any unsafe condition resulting from the tanker's movements," Vinson explains.

A broader challenge for Lockheed's Skunk Works team is integrating its Stingray concept into the Navy's existing aircraft carrier environment, employing all of the standard equipment used by manned aircraft — a Navy requirement for the Stingray.

As Vinson observes, the Navy is the lead integrator for MQ-25, responsible for the data links, network and control stations aboard aircraft carriers through which the Stingrays will be remotely piloted and controlled. Lockheed and its competitors are responsible for the air vehicle segment of the program.

He stresses that much of the MQ-25 requirements documentation is devoted to "interface control." Lockheed's design has to "be compatible with the approach the Navy's taking to the air vehicle operator's interface."

Experience working with the Navy to field the F-35C has been "very helpful," Vinson notes, giving Lockheed's MQ-25 team access to a cadre of people with recent insight into "Navy culture."


GA-ASI

▲ **GA-ASI's proposal** for the MQ-25 Stingray.

The MQ-25 must be compatible with the Joint Precision Approach and Landing System, which sends secure signals from three differential GPS receivers located around the deck to provide incoming pilots with a 20-centimeter (7.8-inch) box to touch down on in any weather conditions.

Vinson says that MQ-25 will utilize a version of JPALS that the F-35C is already employing. Boeing, which purchased F/A-18 manufacturer McDonnell Douglas in 1997, points to its experience with JPALS and a set of Navy-developed carrier landing software on the F/A-18s called MAGIC CARPET, short for Maritime Augmented Guidance with Integrated Controls for Carrier Approach and Recovery Precision Enabling Technologies. These efforts "reduce risk for MQ-25 JPALS integration," Boeing says in a statement.

All told, the MQ-25 program could be well on its way, provided the Navy receives the expected funding from Congress. Deptula suggests there might still be time to address some key questions.

"When is the MQ-25 going to turn into a viable ISR strike asset that can be used in actual combat? Is it 2030, 2040, maybe 2060? If you don't invest in overcoming hard challenges up front, you're going to be late. Do we have the time to do that?" he asks.★

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Quake casting

Unlike hurricanes and volcanic eruptions, earthquakes have resisted all efforts at forecasting. Is it folly or the future to think we can solve that problem? Adam Hadhazy explores how satellite instruments may be bringing earthquake forecasting closer to reality.

BY ADAM HADHAZY | adamhadhazy@gmail.com

> **"What we lack right now are real, physical models that tie together what we expect to be happening in the ground with what we expect to be emitted from the surface."**
>
> — Michael Blanpied, United States Geological Survey

Millions of people in a megacity had just taken their first few bites of lunch when the earthquake sirens blared and text alerts went out. The metropolis was already on edge because of the warning issued two days prior, when ground sensors picked up highly elevated strain in a nearby fault line. And now satellites had just detected the telltale atmospheric signatures of an imminent quake.

With perhaps 30 minutes before the devastating shaking would begin, the city went on lockdown. Utilities turned off water and gas lines. The well-practiced populace crouched in the strongest structural portions of their dwellings and workplaces. When the major quake struck just as predicted, though property destruction was severe, few residents lost their lives that day.

Alas, earthquake prediction of this sort cannot be done today. Despite decades of scientific inquiry, the most advanced public warning systems can only send alerts after an earthquake has started, buying a precious few seconds for those away from the epicenter where heavy shaking has yet to reach.

There is renewed hope, however, that humanity need not remain at the mercy of the planet's tectonic spasms. Increasingly powerful investigational abilities offered by Earth-observing satellites, coupled with sensor networks on terra firma, are advancing our knowledge of earthquake potentiation. Researchers are confident in delivering more precise statistics on the frequency of major quakes, allowing for better civic planning, infrastructure hardening and emergency preparedness.

Some scientists, meanwhile, still hold out hope for genuine, real-time prediction, like in our fictional scenario. Ask most seismologists, though, and they will flatly assert that pinpointing when an earthquake of a particular magnitude will rip forth is — and will always be — impossible. Unlike the clouds and air masses we can readily measure for meteorological outlooks, the opaque, solid ground underfoot might not offer any hints of what is to come.

"We've learned how to forecast a lot of natural hazards, so for most people, it just stands to reason that there must be something that is predictable about earthquake occurrences," says Michael Blanpied, the associate Earthquake Hazards Program coordinator for the U.S. Geological Survey. Seismology has explained how earthquakes start and propagate, why and where they occur, and what their catastrophic potential is. "But the one thing we have not figured out," Blanpied adds, "is whether there's any indication that the Earth provides about the

▲ **Sentinel-1 satellite radar data** from before and after an earthquake in New Zealand shows the quake caused the ground to move 8 to 10 meters, resulting in landslides and a tsunami.
European Space Agency

timing of large earthquakes."

Some scientists outside the seismological consensus think that our world does in fact whisper its subterranean secrets. "It's 'politically correct' to say that there are no detectable precursors for earthquakes," says Kosuke Heki, a geophysicist at Hokkaido University in Sapporo, Japan. Once a skeptic himself, Heki's recent work on perhaps the most tantalizing and controversial precursor type, involving electromagnetic atmospheric anomalies, has altered his perspective. "What I have seen is quite convincing," he says.

The mainstream skeptics and fringe optimists alike will have their convictions tested as never before by the vast amounts of interlinked information pouring in from sensors in, on and above our inconstant planet. "We now have the ability to analyze vast quantities of data very quickly," says Blanpied. "That alone is giving us tools we didn't have even 10 or 20 years ago."

A sudden shuddering

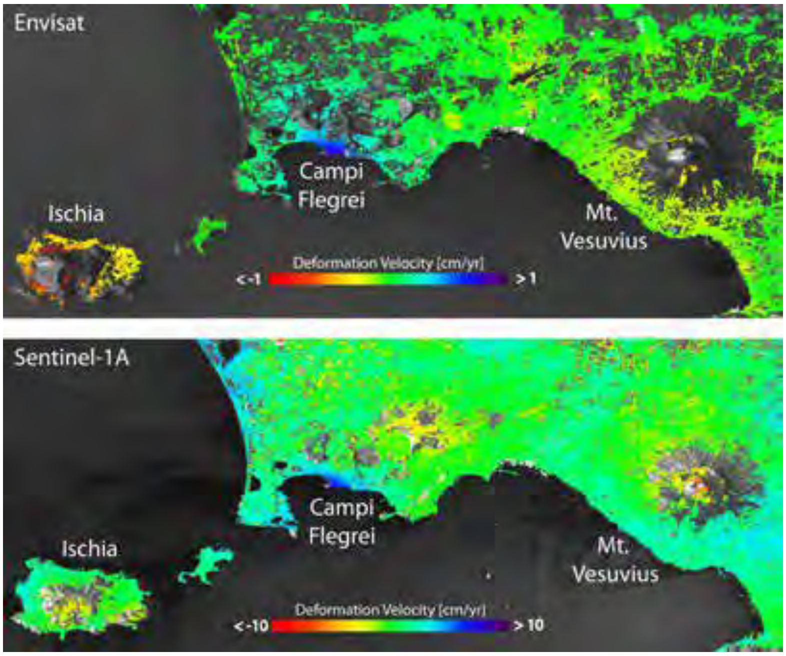
In terms of pure lethality and economic tolls in modern times, no act of nature surpasses the earthquake. The razing of built structures on land, plus the deluge of a tsunami should an earthquake strike offshore, can kill staggering numbers of people. Recent examples include the Indian Ocean earthquake and tsunami in December 2004 (death toll: 280,000) and the January 2010 Haiti earthquake (death toll: 160,000). Earthquakes in China and Japan in the last quarter-century have cost more than even Hurricanes Katrina and Harvey.

The maturing science of seismology in the 20th century worked out that earthquakes happen when great slabs of rock in Earth's crust violently slide past one another at boundaries called faults. Before these sudden shifts, the slabs press together, building up stresses that strain and deform their constituent material. Working out these underlying mechanics offered hope that such disasters might be foretold.

A prime example of how this promise spectacularly fizzled is a place that bills itself as the "earthquake capital of the world": Parkfield, California. This tiny, unincorporated community — population 18 — is situated right on the San Andreas Fault a couple of hundred miles northwest of Los Angeles, where the infamous boundary between two tectonic plates wends through the Southern Coast Range mountains.

Between 1857 and 1966, the Parkfield area experienced several sizeable magnitude 6 earthquakes at remarkably regular intervals, averaging 22 years apart. Recognizing this, the USGS partnered with California's state geological agency on the Parkfield Earthquake Experiment in the 1980s. Earthquake experts publicly agreed on there being a higher than 90 percent chance that a significant quake would rumble the region by 1993. At last, seismologists believed they would catch an earthquake in the act, ushering in an era of short-term prediction.

Scientists threw the seismological equivalent of the kitchen sink at Parkfield, peppering the landscape with tools-of-the-trade including seismometers, which measure ground motion; strainmeters, which measure ground deformation; creepmeters, amusingly named and which measure ground displacement; and magnetometers, which measure magnetic fields



Surface deformation near Italy's Bay of Naples is visible in images created from Envisat radar data from 2002 to 2010 (top) and from Europe's Sentinel-1A in 2014 and 2015. Redder colors indicate loss of elevation while more violet colors represent a gain of elevation relative to the satellite. The Sentinel satellite data provide denser spatial coverage, leading to an improvement in deformation mapping of the region's three chief volcanic complexes: Mount Vesuvius, the Phlegraean Fields (labeled "Campi Flegrei"), and Ischia island.

European Space Agency

associated with ground stress. "Parkfield was identified as the best place to capture an earthquake," says Blanpied. "It became the most heavily scientifically instrumented patch of earth on the planet."

Also brought to bear, as it was becoming increasingly available for civilian use in the late 1980s, was the GPS constellation. Triangulating signals between a constellation of satellites and receivers on Earth establishes the receiver's precise location. The technology is ideal for tracking the slow movements of expanses of Earth's crust over time and, should an earthquake occur, measuring the displacement of receiver sensors, indicating just how much the ground shifted — all of which ties back into geophysical models of earthquake behavior.

As the science world watched and waited, though, Parkfield's due-by earthquake date came and went. It was not until 2004 that a significant mag-6.0 temblor finally broke out. Worse still, there was no warning; the suite of instruments failed to register anything unusual.

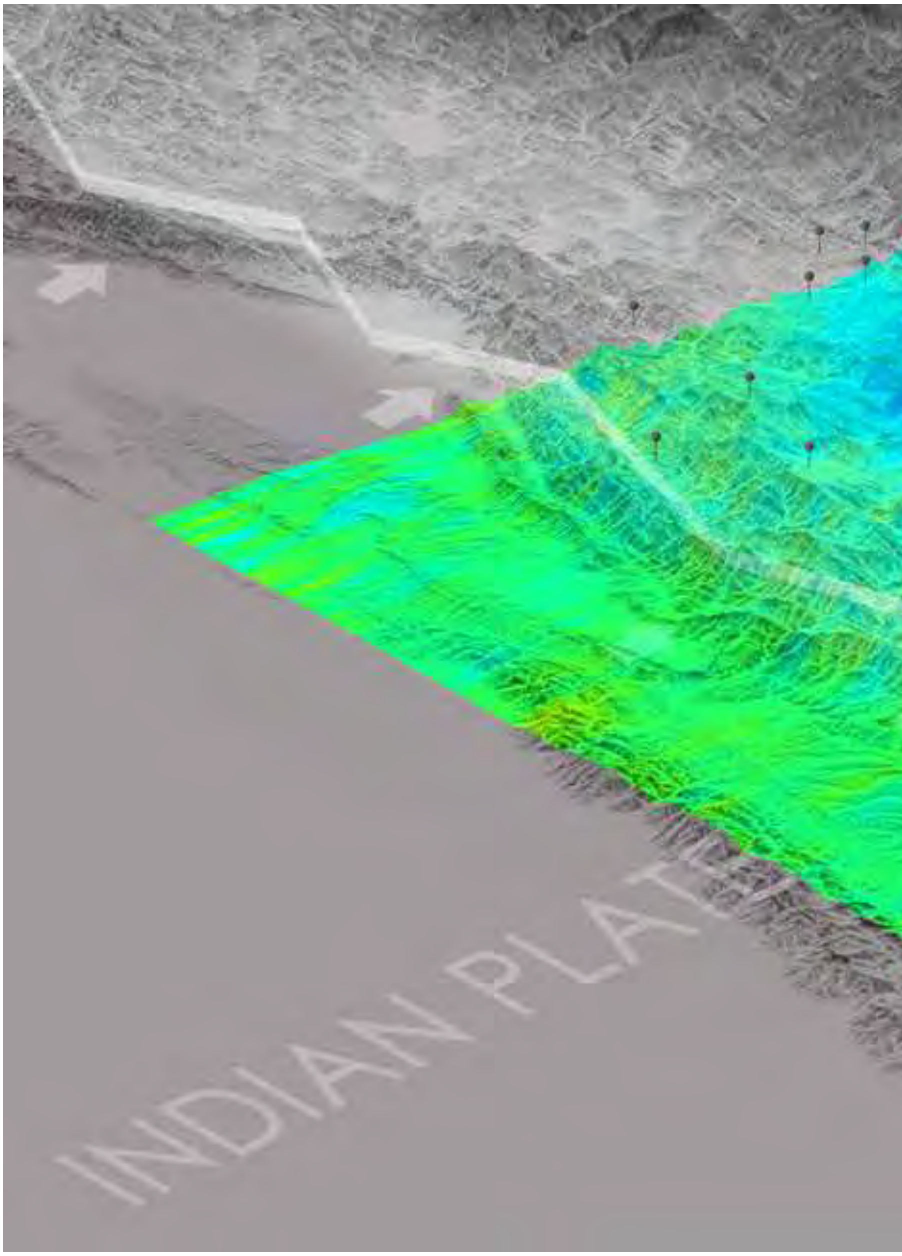
A (space) bird's-eye view

Even though the Parkfield experiment did not pan out, it helped pave the way for multifaceted earthquake study projects that increasingly use space instruments. One example is the Plate Boundary Observatory. It consists of 1,100 GPS sensors and other monitoring equipment primarily placed from Alaska's Aleutian Islands through the western United States and down into Baja California. For more than a decade, the integrated sensor network has monitored the movements of the Pacific and North American tectonic plates, two of the giant jigsaw pieces that compose our planet's crust and at whose fault boundaries some of the largest quakes can occur. The project's funding is sunsetting this year, but continuing analysis of its data haul will seek clues about the long-term evolution of continent-scale landmasses and their associated seismic hazards.

Another of these efforts is run by the United Kingdom-based Centre for Observation and Modelling of Earthquakes, Volcanoes and Tectonics, or COMET. The project receives data from the European Space Agency's twin Sentinel-1 satellites, which were launched in 2014 and 2016 into polar orbits. The spacecraft scan the Earth in cloud-penetrating microwaves, generating 3-D maps via an Interferometric Synthetic Aperture Radar, or InSAR. It combines multiple radar images obtained at different times, tracking any movement and deformation of the ground to a sensitivity of a single millimeter over the span of a year — a dramatic improvement over satellite capabilities from the early 2000s. These observations reveal which areas of rock are elastically bending, storing up energy.

"Seismologists say earthquakes cannot be predicted, because seismologists cannot predict them."

— Friedemann Freund, NASA's Ames Research Center



▼ Lay-of-the-land changes captured by Europe's Sentinel-1A satellite after a 2015 quake in Nepal. The white line running diagonally through the image is the fault line between the Eurasian (top) and the Indian tectonic plates. Blue areas indicate uplift of 0.8 meters toward the satellite, while yellow indicates gradual sinking.
European Space Agency

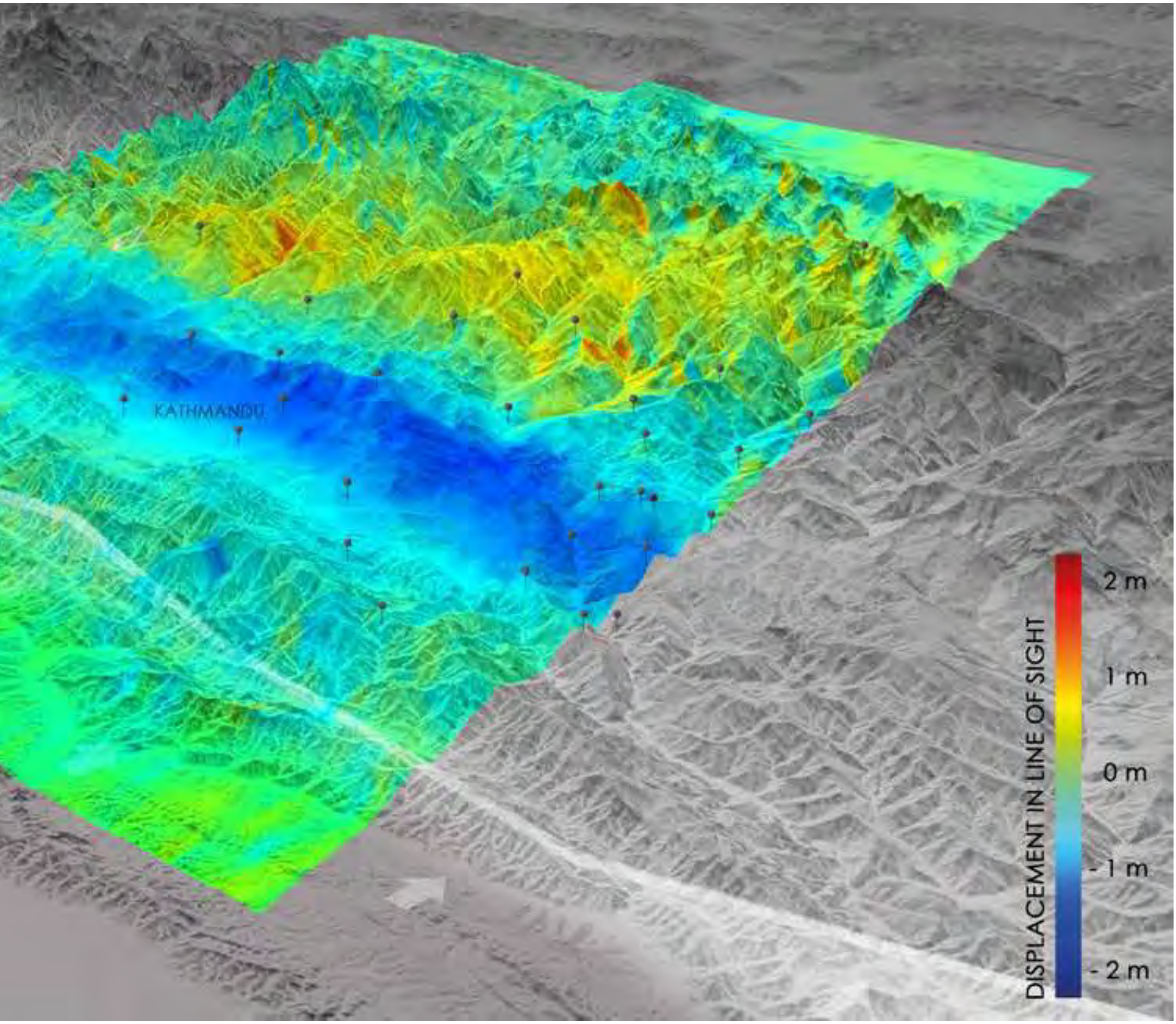
When the bent rock eventually snaps back into place, it will unleash an earthquake.

"Satellite data has revolutionized this field," says Alex Copley, a lecturer at the University of Cambridge who oversees the earthquakes and tectonics portion of COMET. By comparing the deformation data with the timing of past earthquakes, Copley says researchers can make very rough estimates of when the next major event in a location might occur. "This information can form the key input into developing earthquake-proof infrastructure and dramatically reduce the future loss of life from these events," says Copley.

From ballparking to pinpointing

Besides honing traditional seismology's probabilistic approach to long-term earthquake forecasting, satellites might just help crack open a window into more real-time, predictive approaches. Many anecdotal reports of earthquake precursors, including claims of unusual animal behavior such as elephants fleeing for higher ground, as well as aurora-like "earthquake lights," have of course suffered for lack of eyewitness reliability.

Yet under satellites' growingly sensitive and steady gaze, Japan's Heki and others suggest that traditional seismologists may be looking in the wrong place. Somewhat counterintuitively, they should be looking hundreds of kilometers up in the sky where dangerous activity deep underground actually expresses itself. Heki's research had initially focused on the atmospheric pressure chang-



Scripps Institution of Oceanography

GPS stations with seismic and meteorological sensors are part of the process for tracking terrain movements.

es and ionospheric disturbances wrought by earthquakes as they happen. While studying the monster 9.0 Tohoku earthquake that struck in March 2011 off the coast of Japan, Heki noticed something strange happening before the quake got underway. Forty minutes prior, GPS had recorded an increase in total electron content, the sum of electrons along the line of sight connecting a ground station to a satellite.

Now, Heki knew that total electron content is in constant flux due to spurts of geomagnetic activity, for instance. Curious, though, he looked back at historical data for a series of quakes over recent decades. Lesser quakes in the 6- and 7-magnitude range showed no anomalies over the portion of the atmosphere above what would become their epicenters. But major quakes with magnitudes above 8.0 often exhibited similar total electron count enhancements as Tohoku. Crucially, the strength of the anomaly and appearance times before quake initiation sunk or rose in tandem with magnitude, making it hard to chalk it all up to just natural electron count variation. "I'd never seen such a clear precursor before," Heki says.

He is hardly alone in spotting puzzling pre-quake atmospheric activity with spacecraft. The Swarm for earthquake study, or SAFE project, relies on the European Space Agency's three-satellite Swarm constellation. Launched in 2013, Swarm's mission is to precisely measure Earth's magnetic field, adding another earthquake investigatory angle to GPS and ground-mapping satellites. SAFE has reported on magnetic field and electron density anomalies appearing before several larger earthquakes in the last few years. "The results show that there is clear significant statistical correlation between these anomalies and the earthquakes," says Angelo de Santis, the leader of SAFE and the director of research at the National Institute of Geophysics and Volcanology in Rome.

Connecting what's above with what's below

Numerous other reports of potential precursors continue cropping up in the literature. The USGS' Blanpied agrees that some of these signals are "intriguing," but that far more work needs to be done to flesh out the supposed mechanisms behind them. "People have made a lot of observations on the ground and from satellites and have tried to correlate those with the occurrences of large earthquakes," he says. "What we lack right now are real, physical models that tie together what we expect to be happening in the ground with what we expect to be emitted from the surface."

Heki and others do not think it implausible that subterranean seismic activity could have measurable effects a couple of hundred kilometers up into the ionosphere, the upper layer of Earth's atmosphere where many anomalies are detected. One

INDUCED EARTHQUAKES

A group of scientists created the Human-induced Earthquake Database, or HiQuake, to track earthquakes that were caused at least partially by human activities, such as mining and water reservoirs. The database and other resources are available at inducedearthquakes.org.

AusAID

such proposed linkage is from the intense stressing of rocks ahead of an earthquake. Friedemann Freund, a senior researcher at NASA's Ames Research Center in Mountain View, California, and an adjunct professor of physics at San Jose State University, has shown in the lab how stressed rocks can act like a semiconductor battery.

When compressed, chemical peroxy bonds in the rocks break, drawing in negatively charged electrons. A wave of positive electromagnetic charge then propagates as neighboring electrons keep sliding over to fill the just-created charge gaps. The pulses of charge generated in this manner in the lab are weak. But if scaled up to thousands of cubic kilometers of rock, the pulses might just extend through Earth's surface and perturb the ionosphere. Freund's model also calls for several consequences near ground level, including carbon monoxide production related to oxygen (ionized by the stressed rocks) oxidizing organic material in soil. In support, Freund points back to increased carbon monoxide levels at the bottom of the atmosphere detected by NASA's Terra satellite prior to a 7.7-magnitude quake that hit Gujarat, India, in 2001.

As for earthquakes at sea, where the crustal rocks in question are separated from the atmosphere by hundreds of kilometers of water, Freund further suggests that flowing current in ocean beds could generate ultra-low frequency radio waves. These waves might likewise interact with the ionosphere, yielding the sorts of precursors Heki has potentially identified.

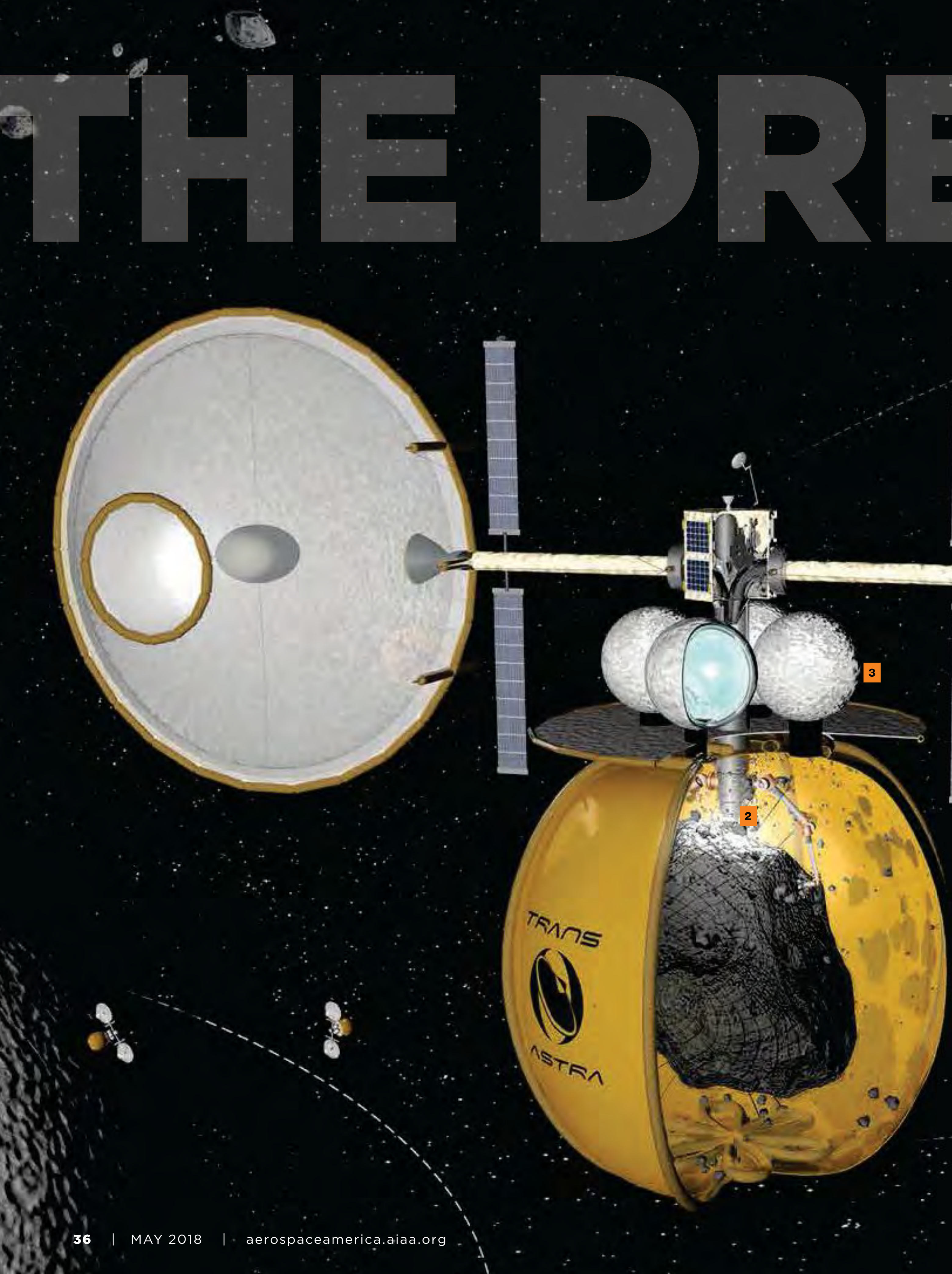
While it is all a bit speculative, ample scientific literature from around the world buttresses the concept of atmospheric earthquake precursors. Freund admits to having received "a lot of flak" for his ideas from the seismology community. But he thinks the field is too hung up on mechanical explanations for earthquake initiation and would benefit from a broader interdisciplinary approach, bringing in chemistry and other overlooked, potentially relevant subspecialties in physics. (Freund, aged 80, cut his teeth in materials science, studying defects in crystals that act like his pre-earthquake stressed rock.) "Seismologists say earthquakes cannot be predicted, because seismologists cannot predict them," Freund says.

In the decades ahead, the deepening analyses of old earthquakes, as well as the plethora of data that unfortunately inevitable, new temblors will provide, should make humanity ultimately safer in the long run. Just maybe, through intensive monitoring at land, sea, and from space, earthquakes could become as predictable as a severe thunderstorm.

"I would say take an open mind to it," says Blanpied. "Take advantage of that massive amount of data and the fantastic earthquake catalogs we now have, really do the numbers, and see what comes out. It may be surprising." ★

▲ Students at a school in Matatirtha, Nepal, take shelter beneath their desks during an earthquake drill. Researchers are studying better ways to prepare communities for earthquakes, but they haven't been able to identify whether the earth gives off signals before an event.

THE DRE



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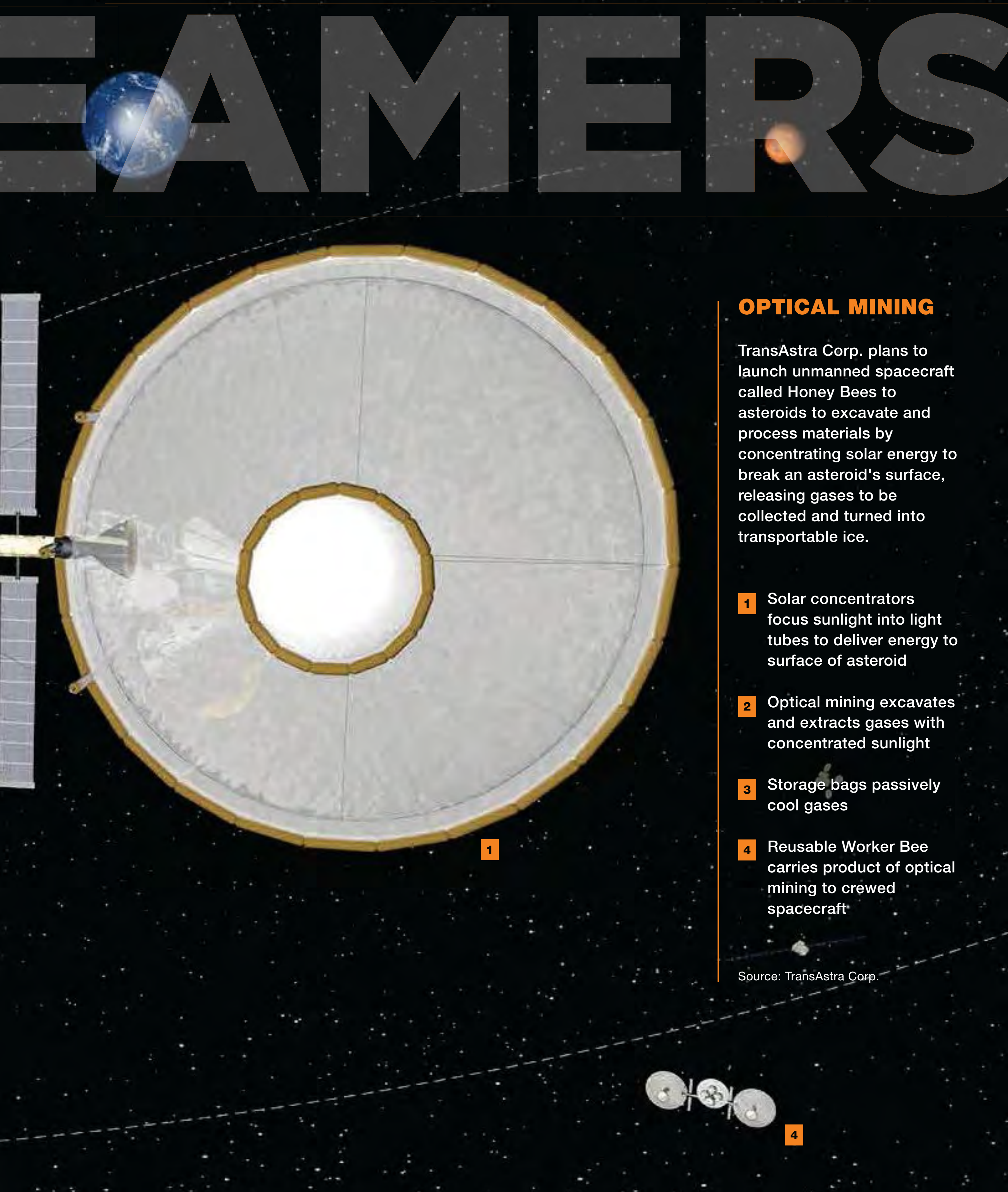


OPTICAL MINING

TransAstra Corp. plans to launch unmanned spacecraft called Honey Bees to asteroids to excavate and process materials by concentrating solar energy to break an asteroid's surface, releasing gases to be collected and turned into transportable ice.

1. Solar concentrators focus sunlight into light tubes to deliver energy to surface of asteroid
2. Optical mining excavates and extracts gases with concentrated sunlight
3. Storage bags passively cool gases
4. Reusable Worker Bee carries product of optical mining to crewed spacecraft

Source: TransAstra Corp.

A cadre of technologists and entrepreneurs think asteroids could be the linchpin for establishing an entire economy in space. Henry Canaday spoke to some of those leading the way.

BY HENRY CANADAY | htcanaday@aol.com

Scientists and engineers operating mostly out of small offices from Los Angeles to Silicon Valley and Europe have a vision of extracting trillions of dollars worth of precious or useful metals from asteroids and bringing them back to Earth. Some of us, they suggest, might even choose to live on these rocky objects.

The desirability and economic benefits of such ventures remain to be seen, but if asteroids and other deep space targets are to be vigorously explored and exploited, doing so will require new ways of thinking about some familiar problems.

First and foremost, success will mean breaking "the tyranny of the rocket equation." If all propellant for deep space exploration must be lifted against Earth's gravity, that requirement severely limits what else rockets can carry, how far they can go and what they can do once they get to their destinations.

So why not create propellant in space by harvesting chemicals from low-gravity asteroids near Earth? Or maybe gather raw materials and manufacture machines in space instead of launching them a few components at a time from Earth. The efficiencies would be enormous, provided the concepts can be proved feasible.

How enormous? A 2017 NASA-funded report, "Stepping Stones: Economic Analysis of Space Transportation Supplied From NEO Resources," estimates that privately developed spacecraft powered by propellants extracted from asteroids could achieve 20 years of vigorous human space exploration and tourism at about a quarter the cost of traditional methods. Specifically, the total cost of exploring the moon's surface, near Earth objects, and Mars would be $90 billion if "commercial best practices" are combined with "asteroid resources," compared to $392 billion without such innovations, the report says.

The report, funded by a NASA grant, was written by former Air Force Research Laboratory adviser Joel Sercel who in 2015 founded the company TransAstra, a two-person firm in Los Angeles, where Sercel is the principal engineer. The firm's board includes former U.S. astronaut and physicist Stanley Love, and the company has received about

$1 million under NASA's Small Business Innovation Research and NASA Innovative Advanced Concepts programs. The company is now seeking its first venture capital funds.

Other companies, including Silicon Valley's Deep Space Industries and Redmond, Washington's Planetary Resources, are eager to tap asteroids for propellant too. And companies such as Los Angeles' SpaceFab are looking further ahead, to manufacturing spacecraft on asteroids with material extracted from them.

Funding

TransAstra's Sercel envisions establishing a public-private partnership with "significant public investment up front and a government commitment to buy extracted propellant at a reasonable price."

In contrast, Deep Space Industries hopes to raise initial investment from high-net-worth individuals and venture capital funds. The company's strategist Peter Stibrany was formerly a system engineer for Canada's Radarsat imaging constellation and designer of components of the International Space Station. While Deep Space Industries focuses on private funding, Stibrany says his company will appreciate any revenue it eventually obtains from selling propellant to national space agencies. "It's always great to get more customers," he says. Deep Space Industries also plans to earn revenue by developing new propellant systems and spacecraft and selling them to space agencies and private companies.

Prospecting

For each potential target, the goal would be to determine the object's composition, diameter, rotation and other features that could impact suitability for mining. By 2020, Deep Space hopes to launch its Prospector-1 spacecraft, which would fly close enough to interesting asteroids to map their surfaces and subsurfaces with visual and infrared imaging. The idea would be to judge the asteroid's value as a source of ingredients for propellants.

TransAstra and Sercel have a different approach. To avoid the expense of sending prospecting vehicles close to candidate asteroids, they propose launching three small space telescopes at a total cost of $50 million as piggybacked payloads into orbits around the sun. This heliocentric constellation would be called Sutter, a reference to American pioneer John Sutter, whose discovery of gold on his property in 1848 precipitated the California Gold Rush of the 19th century.

Graphical processing units on each telescope would rely on matched filter algorithms, a kind of signal processing, to measure composition and other factors. He believes the technique can prospect even fast-moving and faint near Earth asteroids.

By 2020, Deep Space Industries hopes to launch its Prospector-1 spacecraft, which would fly close enough to interesting asteroids to map their surfaces and subsurfaces with visual and infrared imaging.

TransAstra asked Daniel Britt, a professor of astronomy and planetary sciences at the University of Central Florida who once managed the camera on NASA's Mars Pathfinder lander, to assess its plan for the Sutter constellation. "There are various proposals for space-based detectors," Britt says. "Joel's is a good idea."

Sutter prospecting telescopes would first be tested in Earth orbit. And eventually, the three-satellite constellation would be enhanced as Extreme Sutter with more and larger telescopes, including an infrared device.

Once prospecting is done, TransAstra would launch autonomous spaceships called Honey Bees on vehicles such as SpaceX's Falcon 9 to coast to house-sized asteroids. There, lightweight solar reflectors would concentrate heat to fracture the asteroid surface, releasing carbon dioxide, carbon monoxide or methane gasses to be captured in a bag. The reflectors would then be turned around to act as heat shields, so gases can be cooled to transportable ice. The technique, optical mining, is like that proposed for NASA's now-abandoned Asteroid Redirect Mission.

These frozen contents would then be carried by autonomous space tugs called Worker Bees to a crewed space station orbiting between the Earth and moon. Each Worker Bee would be propelled by about 40,000 kilograms of water stored in stainless steel tanks and heated by the solar reflectors. The resulting water vapor would shoot out a nozzle to generate thrust. The crew of the space station would store water as propellant for solar thermal rockets or convert contents into conventional rocket propellants: liquid oxygen-liquid hydrogen or liquid oxygen-liquid methane. Space vehicles from Earth could load up at the facility for Mars or other destinations and avoid carrying so much propellant on the way. The minimal energy required to coast to and approach asteroids with near Earth orbits, then depart and coast back to the propellant facility, makes this an efficient option.

Sercel stresses that optical mining is only one method for extracting water. Another, confidential technique might also extract water. And TransAstra must still determine which propellants are most desirable and cost-effective to make and store at the Earth-orbiting depot.

Deep Space is less specific about its mining plans. It has been designing its proposed small fleet of extraction spacecraft, called Harvestors, for five years. Extraction processes are confidential and partly depend on what Prospector reveals about asteroids. Also confidential is how and where asteroid minerals would be processed. "We have developed what we believe is a very effective system architecture," Stibrany says.

Deep Space's Prospector and Harvestors could be launched on rideshare vehicles such as Falcon 9 and India's Polar Satellite Launch Vehicle or on a dedicated small-satellite launcher. The firm is developing a green bipropellant propulsion system for its spacecraft that Stibrany says will be safer, less expensive and easier to carry on rideshare vehicles

Deep Space Industries would send small Prospector craft to find resources on asteroids.

Bryan Versteeg/
Deep Space Industries

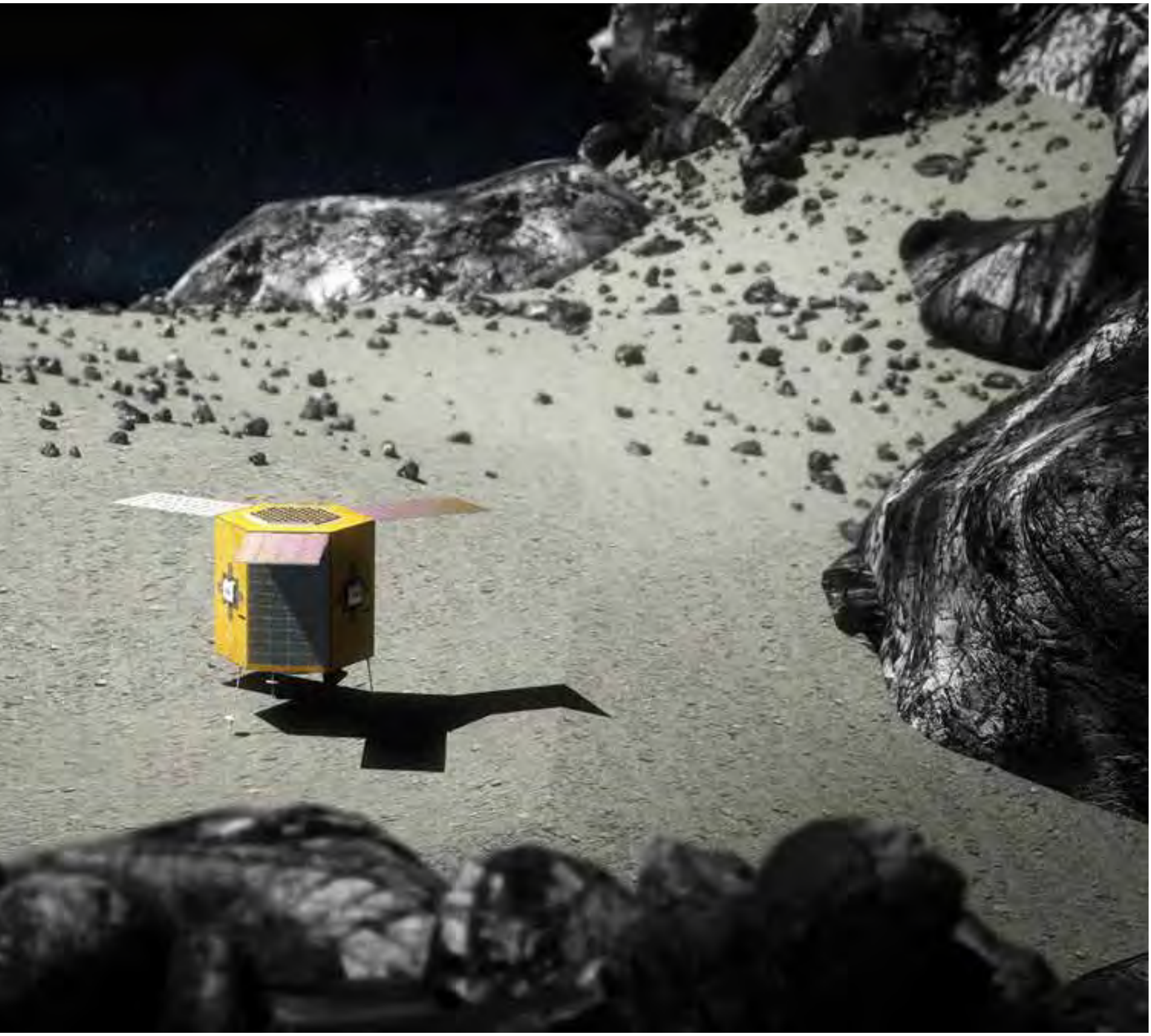
than today's hydrazine monopropellant systems.

Each Harvestor would initially be autonomous, or have what Stibrany calls "supervised autonomy," that is, with humans intervening at critical points and capable of asserting more control over robotic equipment when necessary. He acknowledges that deep space differs from near Earth environments by presenting tougher challenges in propulsion, communications, navigation and surviving radiation.

As for the market, Stibrany says it will materialize gradually and steadily, provided the right strategies are pursued. He says too many business plans envision either demand for materials without a supply infrastructure or the reverse, an expensive supply system without adequate demand. He says Deep Space has an incremental road map that develops supply along with demand. The company already earns revenue from delivering commercial products such as water-based propulsion for small satellites that will support its long-range goals, he says.

"As mining and manufacturing infrastructure in space expands, more materials found on asteroids will become commercially attractive," he predicts.

He speculates that asteroid mining of minerals could ultimately generate sums comparable to the $3 trillion a year now generated by oil, gas and water industries.



> **Propellants gathered from asteroids could provide a less expensive way of shifting geosynchronous satellites into circular orbits.**

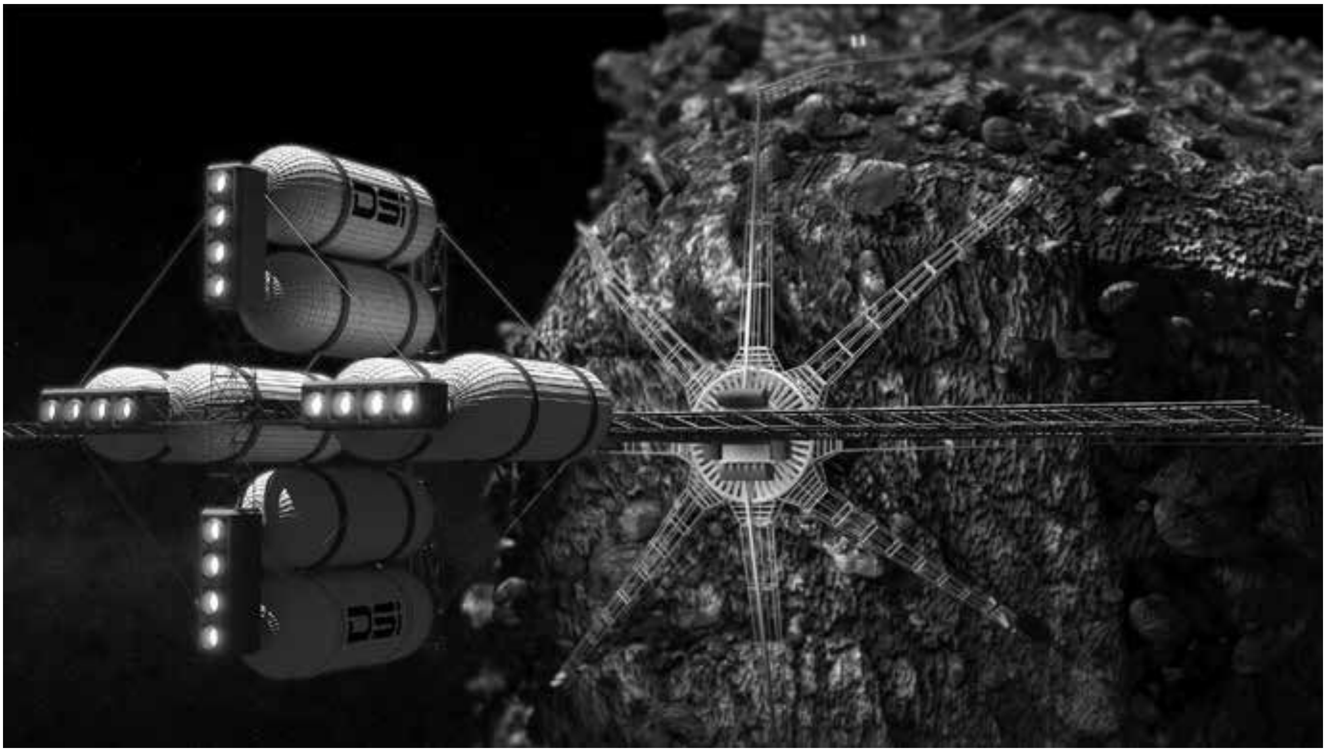
Stibrany believes that the 2017 cancellation of NASA's Asteroid Redirect Mission, which included a robotic spacecraft that would have plucked a boulder from an asteroid, makes information generated by Prospector more attractive to scientists.

What he needs most from governments is speedy regulatory approvals. The Hague Space Resources Governance Working Group, set up in 2014 to consider regulation of space resources, is discussing an international framework for asteroid mining. Stibrany says, "the basic ideas are beginning to gel."

Sercel's TransAstra plan is premised on robust demand for propellant from NASA. Phil Metzger, who worked with NASA's Lunar and Mars Architecture teams and Lunar Exploration Analysis Group, helped develop NASA's technology road map for planetary surfaces and now teaches planetary science at Central Florida, thinks there are other markets. He says propellants gathered from asteroids could provide a less expensive way of shifting geosynchronous satellites into circular orbits after launch than the current technique of firing upper stage rockets.

Making spacecraft in space

Manufacturing spacecraft from materials culled from asteroids is the eventual goal of electrical engineer and computer scientist Randy Chung, CEO of the five-person startup SpaceFab in Los Angeles. Chung started his career at the now-defunct Hughes Aircraft, worked on integrated circuits at storage giant Western Digital in Irvine, California, then managed design of imagers and cameras at Irvine's Conexant. SpaceFab plans to start by launching a space telescope and selling pictures of the Earth and space, unlike current equipment that specializes in either Earth or space imaging. Then Chung plans a mission to bring sample asteroid metals back to Earth. Finally, he wants to mine construction metals from asteroids and manufacture large structures in space.



Bryan Versteeg/Deep Space Industries

▲ **A fleet of Harvestor spacecraft** would extract minerals from asteroids under Deep Space Industries' plan.

SpaceFab is raising seed money through Wefunder.com for a planned launch of its Waypoint telescope in 2019. "Our first step is to build a viable and competitive space telescope business using our unique technology," Chung says. SpaceFab is loading Waypoint with as many features as possible in a low-cost, 12-unit cubesat. It will have three cameras to cover both Earth and space observation and an onboard computer to process images for tracking of asteroids and space debris.

Chung would like to launch his first asteroid mission soon after NASA's Psyche spacecraft, targeted for launch in 2022, begins orbiting the asteroid Psyche 16 in 2026. Psyche 16 is notable as a world made of metal rather than rock or ice, according to Arizona State University, which will lead the mission. Chung believes SpaceFab's mission can get out and back in eight years. Chung expects SpaceX's Big Falcon Rocket will be operational by 2026 and that SpaceFab can get a low-cost rideshare to Mars, then use Mars as a slingshot to the metallic asteroid. He hopes to at least break even by keeping costs low and selling samples of asteroid metals to educational and research institutions. Then his first mining and manufacturing mission would go out in the early or middle 2030s.

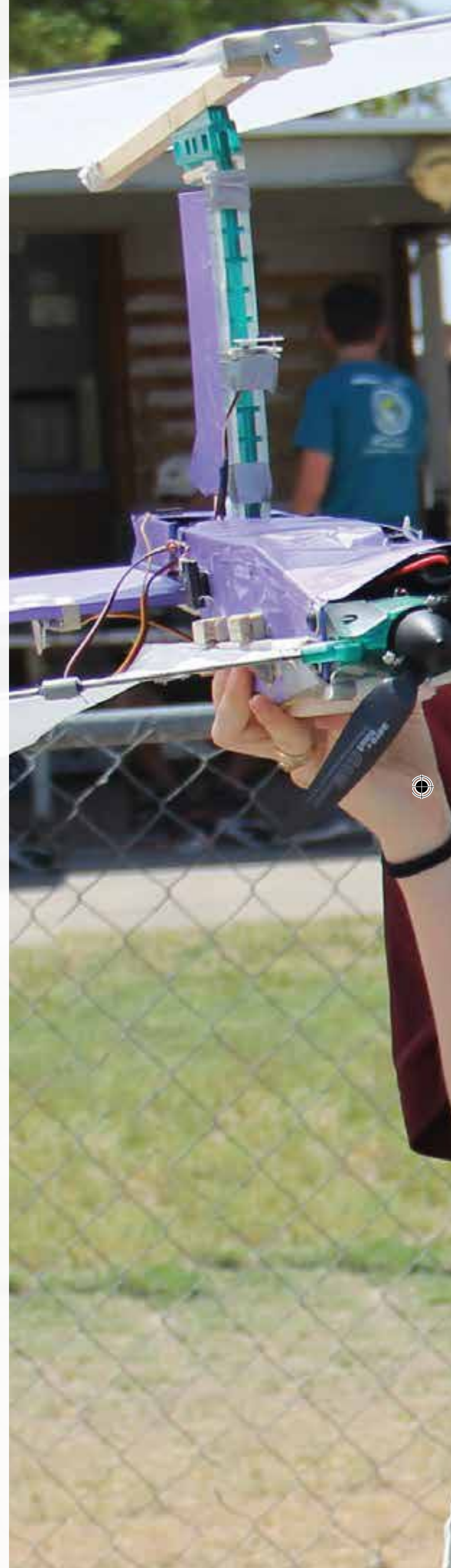
Chung believes iron-nickel-cobalt alloys present in metal asteroids will be highly valuable. "FeNiCo alloy is essentially a form of steel and can make the same kind of things we make from steel here on Earth, such as reinforcing bar, sheet metal, pipes and especially machinery. Once we can make machinery, we can make just about anything," he says. Finding and prospecting will not be necessary as several large metal asteroids are already known, for example, 16 Psyche with possibly 40,000 times the amount of steel produced so far on Earth.

Extraction of alloys would be done on the surface by a simple, electromagnetic process. Chung is relying on pieces of metal, the size of sand grains or pebbles, which can be picked up by electromagnets or sorted with an eddy-current separator. Refining might be as simple as melting small metal pieces with an induction heater and straining out stony pieces.

Refined metal would be fed into an autonomous 900- to 1,800-kg factory to fabricate tools, machinery and structures on the asteroid. This factory would also build more fabrication capacity. Initially, tools including 3-D printers, milling machines, motors and bearings would be sent from Earth. Longer term, even these might be fabricated in space.

Chung estimates a solar-powered, autonomous factory can mine and process 0.5 percent of its mass per day, fabricate 30 percent of its mass annually for customers and increase its capacity 30 percent annually. Production capacity would grow to 23 million kg in 30 years, enough to construct 50 International Space Stations annually.

Unlike TransAstra and Deep Space, SpaceFab would neither mine nor be powered by propellants from asteroids. For propulsion, the company is testing an ion thruster, which creates thrust by accelerating ions with electricity. ★

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BY ADRIAN BEJAN | abejan@duke.edu

PERSONAL AIRCRAFT

Why the revolution won't happen

The aviation industry is excited by the prospects of personal aircraft, sometimes called passenger drones or sky taxis, whisking commuters through the sky. Electrical power, automation and safety are obvious challenges to that vision, but there is a more fundamental issue of physics to contend with. Nature theorist and mechanical engineering professor Adrian Bejan explains.

▲ **For personal aircraft,** the short distance of a commute will not justify the energy expended to get airborne, Adrian Bejan says.

Will personal aircraft be the next big breakthrough as far as popular modes of air transportation go? Will most of us who today drive cars to and from work eventually turn to personal aircraft for our commutes? The answers, simply put, are no.

The problem is that a personal aircraft must expend fuel to get off the ground, to travel a short distance by air, while a runner and an automobile do not have to. Flying is more economical for cruising at longer distances. We see this design clearly in the animal world. When a cormorant needs to travel 10 or 20 meters, it swims. When it needs to travel much farther, it flies and lands kilometers down range. Why, because cruising by air requires less power (useful energy) than moving on water. The energy savings from flying a long distance outweigh the energy penalty of having to rise in the air.

So, flying is for faster travel over long distances. For short distances, the economical movement is on land, and it is slower. We see this in the design of the movement of people among concourses in a large airport, such as Hartsfield-Jackson Atlanta International. Moving from one concourse to a distant one is accomplished by taking "The Plane Train," which is analogous to flight. If one wanted to sweep the area fully, that would be accomplished by the short and slow movement, which is by walking along the concourses perpendicularly to the long and fast Plane Train.

That's my first conclusion, based on years of thinking about the forces that determine how matter, machines and organisms, including humans, will move, or flow, from one place to another, at this moment and into the future. The guiding principle I coined is called the constructal law, a principle of physics I conceived in 1995 to account for design evolution in biology, geophysics and technology. The constructal law accounts for all moving and evolving (morphing) systems, all locomotion, bio and non-bio, human made and not human made,

the rivers, the winds, and the animals in the air, on land and in the water.

All moving things evolve toward designs that facilitate the access of the mover through the ambient, by decreasing the effort of pushing the air or water out of the way. For evolution to happen, the design of the moving system must have freedom to change. Nature is endowed with many properties, and freedom is one of them. This is why evolution and the future happen.

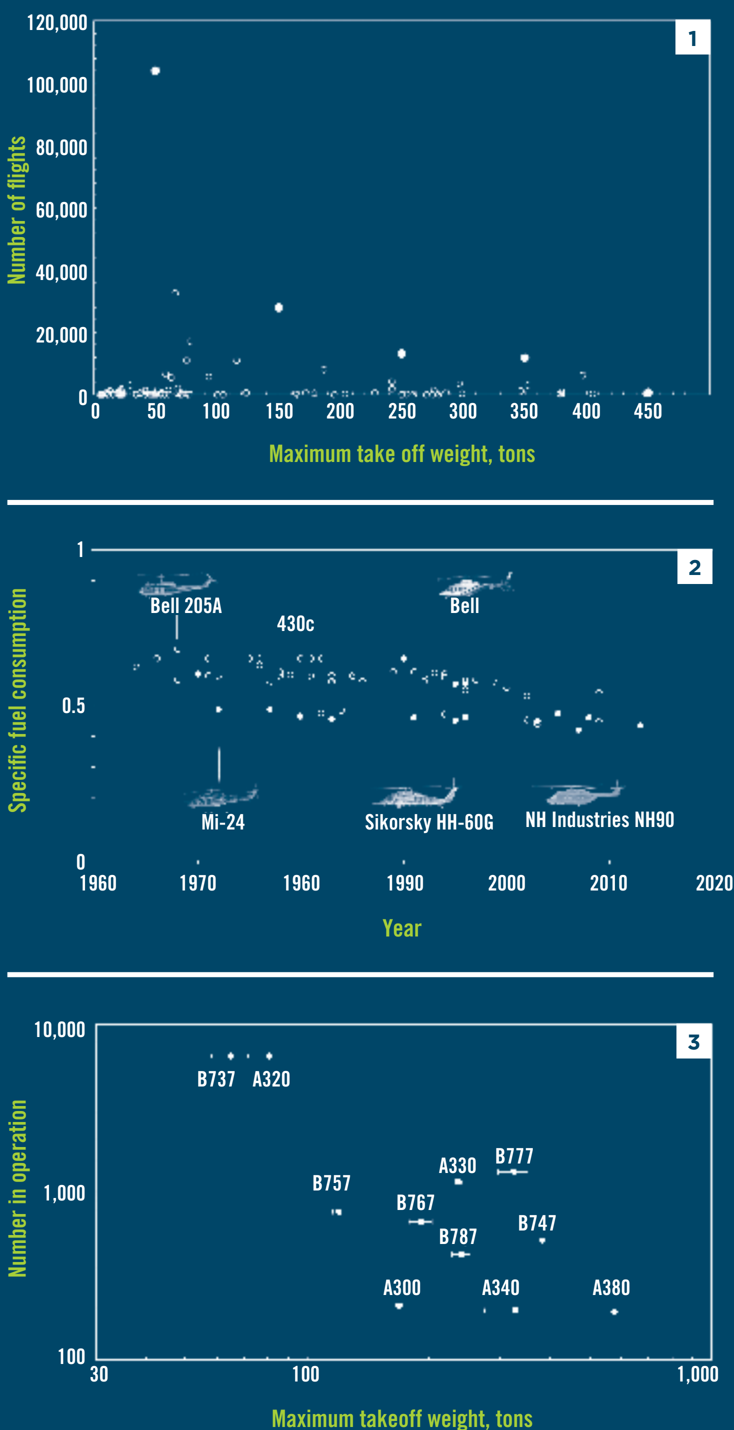
There is more to the power to predict the future of any human add-on, such as the personal aircraft. First, some definitions:

Human flight is only a hundred years old, and it is made possible by the oneness of human and machine. The flying person is encapsulated in the flying machine. Without a flying or other kind of machine, the person remains a walker or a runner. Without the person, the machine does not exist. The current physics and biology literature shows that flying "human and machine" specimens (airplanes of many sizes and types, propeller and jet driven) obey the same relationships between speed and size, and between energy use and size, as all the flying animals, insects, birds and bats.

In the physics that unifies all flyers, whether animal or human, "vehicle" means a self-propelled body that has size and weight. The duck, the prehistoric human, the airplane, and the package-delivering drone are all vehicles, and they conform faithfully to the laws of physics. The same is true of all the land and aquatic vehicles, runners and swimmers. Vehicle is a general concept, it is not necessarily made by humans, or with a person inside.

Every vehicle size has its niche. This is evident in animals, where on the same plot on the world map the large animals are few, and the small are many. The large are faster and travel farther than the small. They all move and live together, on the same nourishing land, in harmony. They are like the population trav-

THE CONSTRUCTAL LAW



Aircraft design is driven by the same physics law that governs nature, says Adrian Bejan. (1) The number of commercial passenger flights during 2016 confirms that there are many small and fewer large in the aircraft world. (2) Over time, more efficient helicopters have become more common. (3) And, among leading groups of aircraft models flying in July 2016, the majority were smaller.

Source: A. Bejan, R. Chen, S. Lorente and C.Y. Chen, "Hierarchy in air travel: Few large and many small," Journal of Applied Physics, Vol. 122, 024904

eling through the Atlanta airport, where the large is only one (the train, traveling long), and the small are the pedestrians on the area that hugs the train line.

Niche is also evident in aviation. We know that in aviation the small aircraft outnumber the large aircraft. The same is true of the number of daily flights taken by small aircraft, compared with the daily flights of large aircraft. From the tree outside my window, the sparrows take off much more frequently than the big owl, the sparrows from branch to branch, the owl from tree to tree.

Superimposed, all the niches filled by flyers and other movers constitute a hierarchy, which means few large and many small, together. Hierarchy is a natural phenomenon.

This is why in the future, all moving individuals, groups and populations will continue to exhibit the natural tendency to evolve toward hierarchical configurations, like all the flows in the channels of a river basin, and in all the air tubes in the lung. The aviation equivalent of these hierarchical flows are the flows that constitute the global air traffic system. The big rivers are the long and fast air corridors populated by larger aircraft. The tributaries and branches are the shorter, slower and denser corridors, which are traveled more frequently by more numerous smaller aircraft.

The physics basis for the existence of the "large" is the phenomenon of economies of scale. It is easier to move a unit mass in bulk (along with many other units, on a big river, animal, truck or airplane) than to move it alone. Finding your way out of a crowded arena, it is easier to move with those in front of you (in a conga line) than to elbow your way through all the other disorganized movers who elbow you.

The "small" also exist because of the reality of physics that movement from one place to another must occur within the constraints of a physical area, just as the blood cells inside the body are constrained by the volume in which they flow. Movers cannot fill an area or a volume when they are all big. To fill a space completely, the interstices that exist between the few large are inhabited by smaller and more numerous movers. The spaces between the smaller are inhabited by the even smaller and the even more numerous.

This is hierarchy, and why it is natural, unstoppable. We see it in geophysical movement, animal movement, human social movement (city traffic, global air traffic), everywhere. No flow system escapes from the laws of nature.

With regard to human flight, this evolutionary trend is already evident, even though flying humans are only in the starting blocks of their evolutionary run. The "human and machine species" is a new species, unlike the animal flyers, runners and swimmers. Yet, even as early as now, the aircraft that carry humanity

When contemplating personal aircraft, one should imagine a flying design that is much bigger than the biggest birds, that is a "human and machine specimen" the size of which is mostly machine.

around the globe every day are exhibiting the expected hierarchy, the large are few and the small are many.

The economies of scale phenomenon is also on full display. Large or small, aircraft are evolving toward easier access through the air, which means more economically, more efficiently, with less fuel consumption per passenger and kilometers flown. During the past five decades, the evolution of helicopters has shown a steady decrease in specific fuel consumption. The evolution of commercial jets has been toward less fuel spent for one seat and 100 km flown. On an average, we see a 1.2 percent annual decrease in fuel burn per seat, according to the 2005 study "Fuel efficiency of commercial aircraft — an overview of historical and future trends" by the Netherlands National Aerospace Laboratory.

A new hierarchical design of movement on Earth does not eliminate the existing hierarchical designs of movement. The new hierarchy joins the old, and what works is kept. Animal flyers rose from land but did not displace the land animals. Much earlier, the land animals did not eliminate the swimmers.

And so, personal aircraft will be a new mode of locomotion for some, but not one that will replace the existing modes. This physics is important to know, because the emerging hierarchy can help us predict how few the even bigger models will be and how more numerous the smaller models will be, naturally.

So, as the globe is covered more and more completely by human movement, the smaller patches of the Earth's surface will be traveled by vehicles that are smaller and more numerous than the vehicles that carry the same human flow over larger areas. Among vehicles that carry a single passenger, the personal aircraft will not eliminate the automobile, the bicycle, the runner and the walker.

Furthermore, the personal aircraft will be considerably bigger than one human body. By invoking the constructal law one can show that the fraction of the mass occupied by the lifting organs in the overall body mass that moves should increase with the body size. This is evident in terrestrial animals, where the lifting organs are the legs.

In animal flyers, the lifting organs are the wings. How they dominate the design is evident, from the hummingbird and the barn swallow, to the condor and the pterodactyl. The reality that goes overlooked is that design is another name for size. The large design is not a blown up version of the small. The large size has its own architecture.

In human flyers, the lifting organ is the aircraft itself, wings and all. Therefore, when contemplating personal aircraft, one should not imagine a blown up version of the humming bird, the toy airplane, and the amazon package with a propeller on top. One should imagine a flying design that is much bigger than the biggest birds, that is a "human and machine specimen" the size of which is mostly machine, not the naked human body. Expending energy getting airborne will not be efficient for travel over the relatively short distance of a commute.

Beyond that, it remains to be seen to what extent the small and many air vehicles will join the small and many land movers. None of these features of movement will deviate from the fewer-and-larger rule.

Personal aircraft and package-delivery drones will not buzz all over our heads. They will fly along hierarchical paths that are defined and regulated (by safety laws and traffic convention, because of the human urge to survive), with rules, rewards and penalties. This hierarchical air design will happen naturally, the same way as the city traffic, the air traffic web and the bird migration corridors.

It's good to raise questions about inevitability. What is inevitable in design evolution is that evolution is governed by physics principles including economies of scale, hierarchy, the constructal law, and the common sense reality that what works is kept. This means widespread adoption of personal aircraft is not inevitable and, in fact, won't happen. ★

Adrian Bejan is a mechanical engineering professor at Duke University in North Carolina and author of "The Physics of Life: The Evolution of Everything" (St. Martin's Press, New York, 2016).

AIAA Bulletin

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

Calendar

Notes About the Calendar

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

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2018			
1 May	2018 Fellows Dinner	Crystal City, VA	
2 May	Aerospace Spotlight Awards Gala	Washington, DC	
8–10 May	AIAA DEFENSE Forum (AIAA Defense and Security Forum) Featuring: – Missile Sciences Conference – National Forum on Weapon System Effectivenss – Strategic and Tactical Missile Systems Conference	Laurel, MD	30 Nov 17
10–11 May	Aerospace Survivability Course	Laurel, MD	
28–30 May †	25th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (Contact: www.elektropribor.spb.ru)	
28 May–1 Jun †	SpaceOps 2018: 15th International Conference on Space Operations	Marseille, France (Contact: www.spaceops2018.org)	6 Jul 17
31 May	DirectTech Webinar—High Order CFD Methods: Results and Advancements from the 5th International Workshop	Virtual (aiaa.org/onlinelearning)	
4–8 Jun†	DATT (Defense & Aerospace Test & Telemetry) Summit	Orlando, FL (www.dattsummit.com)	
7 Jun	DirectTech Webinar—DEMAND for UNMANNED® presents: Aircraft and Rotorcraft System Identification Engineering Methods for UAV Applications	Virtual (aiaa.org/onlinelearning)	
23–24 Jun	Design of Electric and Hybrid-Electric Aircraft Course	Atlanta, GA	
23–24 Jun	Missile Aerodynamics Course	Atlanta, GA	
23–24 Jun	OpenFOAM® Foundations Course	Atlanta, GA	
23–24 Jun	Optimal Design in Multidisciplinary Systems Course	Atlanta, GA	
23–24 Jun	Practical Design Methods for Aircraft and Rotorcraft Flgiht Control for Manned and UAV Applications with Hands-on Training Using CONDUIT® Course	Atlanta, GA	
23–24 Jun	5th AIAA Workshop on Benchmark Problems for Airframe Noise Computations (BANC-V)	Atlanta, GA	
25–29 Jun	AIAA AVIATION Forum (AIAA Aviation and Aeronautics Forum and Exposition) Featuring: – AIAA/CEAS Aeroacoustics Conference – Aerodynamic Measurement Technology and Ground Testing Conference – Applied Aerodynamics Conference – Atmospheric Flight Mechanics Conference – Atmospheric and Space Environments Conference – Aviation Technology, Integration, and Operations Conference – Flight Testing Conference – Flow Control Conference – Fluid Dynamics Conference – Joint Thermophysics and Heat Transfer Conference – Modeling and Simulation Technologies Conference – Multidisciplinary Analysis and Optimization Conference – Plasmadynamics and Lasers Conference	Atlanta, GA	9 Nov 17
25–29 Jun†	15th Spacecraft Charging Technology Conference (SCTC)	Kobe, Japan (Contact: http://www.org.kobe-u.ac.jp/15sctc/index.html)	
3–6 Jul†	ICNPAA-2018 - Mathematical Problems in Engineering, Aerospace and Sciences	Yerevan, Armenia (Contact:: www.icnpaa.com)	
7–8 Jul	Emerging Concepts in High Speed Air-Breathing Propulsion Course	Cincinnati, OH	
7–8 Jul	Fundamentals of Gas Turbine Engine Aerothermodynamics, Performance, and Systems Integration Course	Cincinnati, OH	
7–8 Jul	Liquid Atomization, Spray, and Fuel Injection in Aircraft Gas Turbine Engines Course	Cincinnati, OH	
7–8 Jul	Liquid Rocket Engines: Fundamentals, Green Propellants, and Emerging Technologies Course	Cincinnati, OH	
7–8 Jul	Propulsion of Flapping-wing Micro Air Vehicles (FMAVS) Course	Cincinnati, OH	

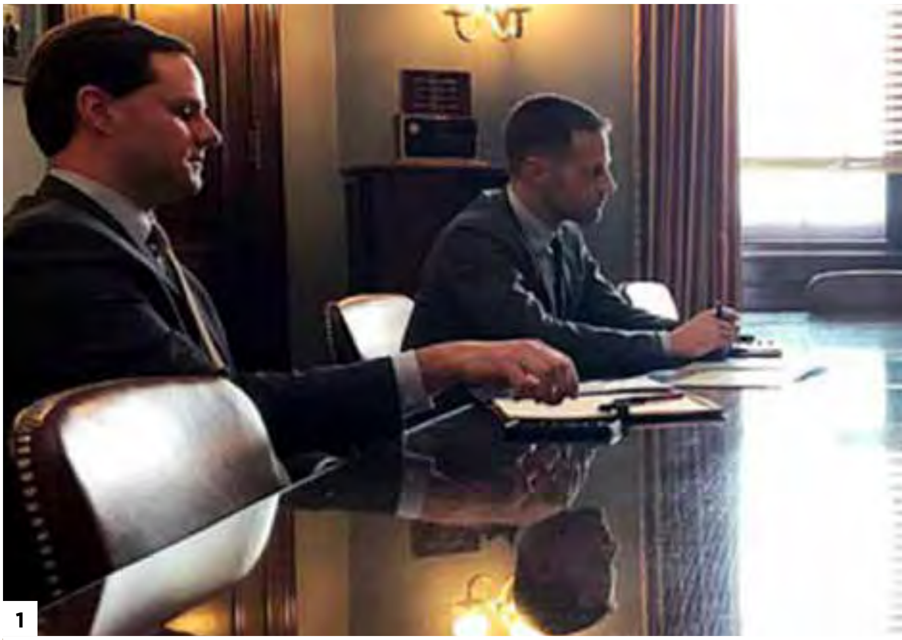
AIAA Continuing Education offerings

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

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
7–8 Jul	AIAA Complex Aerospace Systems Exchange (CASE) Workshop	Cincinnati, OH	
7–8 Jul	4th Propulsion Aerodynamics Workshop	Cincinnati, OH	
8 Jul	Enabling Technologies and Analysis Methods for More-, Hybrid-, and All-Electric Aircraft Course	Cincinnati, OH	
9–11 Jul	AIAA Propulsion and Energy Forum (AIAA Propulsion and Energy Forum and Exposition) Featuring: – Joint Propulsion Conference – International Energy Conversion Engineering Conference	Cincinnati, OH	4 Jan 18
12–13 Jul	AIAA/IEEE Electric Aircraft Technologies Symposium	Cincinnati, OH (aiaa.org/eats)	15 Feb 18
19–23 Aug†	2018 AAS/AIAA Astrodynamics Specialist Conference	Snowbird, UT (www.space-flight.org)	
15–16 Sep	Integrating Program Management and Systems Engineering Course	Orlando, FL	
16 Sep	Space Standards and Architectures Course	Orlando, FL	
17–19 Sep	AIAA SPACE Forum (AIAA Space and Astronautics Forum and Exposition) Featuring: – Complex Aerospace Systems Exchange – International Space Planes and Hypersonic Systems and Technologies Conference	Orlando, FL	8 Feb 18
1–5 Oct†	69th International Astronautical Congress	Bremen, Germany	
2019			
7 Jan	AIAA Associate Fellows Awards Ceremony and Dinner	San Diego, CA	
7–11 Jan	AIAA SciTech Forum (AIAA Science and Technology Forum and Exposition) Featuring: – Adaptive Structures Conference – Aerospace Sciences Meeting – Atmospheric Flight Mechanics Conference – Information Systems — Infotech@Aerospace Conference – Dynamics Specialists Conference – Guidance, Navigation, and Control Conference – Modeling and Simulation Technologies Conference – Non-Deterministic Approaches Conference – Structures, Structural Dynamics, and Materials Conference – Spacecraft Structures Conference – Wind Energy Symposium	San Diego, CA	11 Jun 18
13–17 Jan†	29th AAS/AIAA Space Flight Mechanics Meeting	Ka'anapali, HI	14 Sep 18
28–31 Jan†	65th Reliability and Maintainability Symposium (RAMS 2019)	Orlando, FL (www.rams.org)	
2–9 Mar†	2019 IEEE Aerospace Conference	Big Sky, MT (www.aeroconf.org)	
3–5 Apr†	5th CEAS Conference on Guidance, Navigation & Control (2019 EuroGNC)	Milan, Italy (Contact: www.eurognc19.polimi.it)	
14 May	AIAA Fellows Dinner	Crystal City, VA	
15 May	AIAA Aerospace Spotlight Awards Gala	Washington, DC	
20–23 May†	25th AIAA/CEAS Aeroacoustics Conference (Aeroacoustics 2019)	Delft, The Netherlands	1 Oct 18
27–29 May†	26th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (Contact: www.elektropribor.spb.ru/icins2019/en)	
10–13 Jun†	18th International Forum on Aeroelasticity and Structural Dynamics	Savannah, GA (Contact: http://ifasd2019.utcdayton.com)	

AIAA Members Advocate for Aerospace on Capitol Hill

AIAA's 21st annual Congressional Visits Day (CVD) program was held on 21 March. CVD offers professional and student members an experience that opens their eyes to the inner workings of the legislative process, enhances their career development, and presents the opportunity to be a champion for the aerospace community. Despite a late winter storm that brought snow to the DC area, 92 members representing 29 different states attended the event. A large majority of the participants were student members and young professionals. The attendees, who were divided into state teams, visited approximately 185 congressional offices to help promote the Institute's key issues and raise awareness of the long-term value that science, engineering, and technology bring to the nation. A reception was held on the Hill that evening.



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1 Team Alabama. 2 CVD participants with Rep. Rick Larsen (D-WA). 3 Team Alabama with Sen. Doug Jones (D-AL). 4 Team Nevada with Rep. Ruben Kihuen (D-NV). 5 Team South Carolina with Rep. Mark Sanford (R-SC). 6 Team Massachusetts with Rep. Joe Kennedy (D-MA). 7 CVD participants outside the U.S. Capitol. 8 Team California with Rep. Steve Knight (R-CA).

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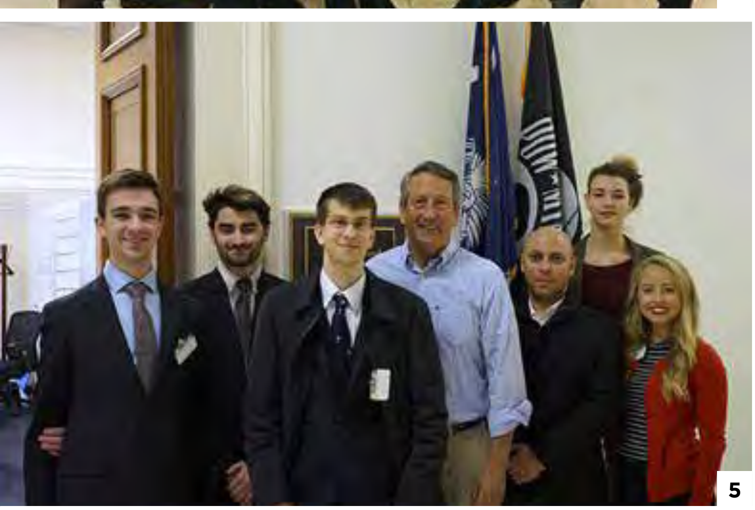

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2018 AIAA Election Results

AIAA is pleased to announce the results of its 2018 Council of Directors election.

The newly elected council members are:

- **Director–Aerospace Sciences Group**
  D. Brett Ridgely

- **Director–Aerospace Design & Structures Group**
  Carlos Cesnik

- **Director–Region III**
  Daniel Jensen

- **Director–Region VI**
  Jeffery Puschell

The newly elected council members will begin their terms of office on **3 May 2018.**

AIAA Journals Announcement

To leverage advances in publishing technology, AIAA has been transitioning our technical journals away from the traditional print format over the past few years. This process will be complete in January 2019, when *Journal of Aircraft (JA), Journal of Guidance, Control, and Dynamics (JGCD), Journal of Spacecraft and Rockets (JSR), Journal of Propulsion and Power (JPP),* and *Journal of Thermodynamics and Heat Transfer (JTHT)* move to an online-only format. The final 2018 issue for each of these journals will be the last issue distributed in print.

Print customers transitioning to the online format will be able to maximize the user experience with research tools and access to the most up-to-date versions of articles in Aerospace Research Central. All of AIAA's technical journals will continue to publish high-quality, original research papers spanning the spectrum of aerospace science and technology and reporting on the most critical aerospace advances.

Nominate Your Peers and Colleagues!

NOW ACCEPTING AWARDS NOMINATIONS

PUBLICATION/LITERARY AWARDS

- Children's Literature Award
- Gardner-Lasser Aerospace History Literature Award
- History Manuscript Award
- Pendray Aerospace Literature Award
- Summerfield Book Award

SERVICE AWARDS

- Diversity and Inclusion Award
- Sustained Service Award

TECHNICAL AWARDS

- Aerospace Software Engineering Award
- de Florez Award for Flight Simulation
- Excellence in Aerospace Standardization Award
- Information Systems Award
- Mechanics and Control of Flight Award

Please submit the four-page nomination form and endorsement letters to **awards@aiaa.org** by **1 July 2018**.

For more information about the AIAA Honors and Awards Program and a complete listing of all the AIAA awards, please visit **aiaa.org/HonorsAndAwards**.

AIAA
Shaping the Future of Aerospace

News

Students from Abuja, Nigeria, Participate in FIRST LEGO League Challenge

▲ The Geniuses Team sponsored by the AIAA Foundation showing off their Hydro Dynamics project and core valves.

Every year, the FIRST LEGO League releases a challenge, which is based on a real-world scientific topic, and puts students' problem solving and critical thinking skills to the test. The 2017/2018 challenge is about Hydro Dynamic, where teams learned all about water – how we find, transport, use, or dispose of it. Students ages 9 to 16 from various government and private schools throughout 80 countries made a splash with Hydro Dynamics.

On 24 February, students came together in Abuja, Nigeria, to participate in this challenge at Baze University. Teams built, tested, and programmed an autonomous robot using LEGO MINDSTORM technology to solve a set of missions in preparation for the Robot Games. Throughout their experience and problem-solving processes, teams operated under the FIRST LEGO League signature set of core values, celebrating discovery, teamwork, and professionalism.

The Geniuses Team from the Odyssey Educational Foundation was one of ten schools that participated in this particular challenge. The team received an AIAA Foundation FIRST® LEGO® League Grant that was supported by The Boeing Company. They used the funds from the grant to purchase a robot for the competition.

The AIAA Foundation is proud to support programs such as this and congratulates all of the teams for their participation. Applications for the 2018 AIAA Foundation FIRST® LEGO® League Grant Program will be accepted 11 May–31 August 2018. For more information please visit aiaa.org/FIRSTGrants.

Seven AIAA Members Included in Langley Research Center Hall of Honor Class of 2017

In 2017, the Langley Research Center NACA/NASA Hall of Honor honored its second class of inductees. The Hall of Honor was conceived to pay tribute to individuals who built exemplary careers at the NACA Langley Memorial Aeronautical Laboratory/NASA Langley Research Center, and it formally recognizes those persons whose contributions have had the most sustained and far-reaching influence on the leadership, direction, mission, and capabilities of the center and/or whose work at Langley enabled unprecedented and fundamental advancements in either a scientific or engineering field and made significant contributions to the U.S. aerospace industry for commercial and military aircraft and/or spacecraft. The hall provides a focused opportunity for NASA Langley employees, retirees, and the aerospace community to reflect on the notable contributions of these who were instrumental in the sustained and exceptionally important successes of Langley.

The first induction took place in 2015 to mark the 100tth anniversary of the creation of NACA, and the second induction of 18 honorees took place in June 2017, as part of the NASA Langley Research Center Centennial celebration. Many of these honorees and their contributions are prominently reflected in two new books on this 100-year history: *The Unknown and Impossible: How a Research Facility in Virginia Mastered the Air and Conquered Space* (Tamara Dietrich, Mark St. John Erickson and Mike Holtzclaw, The Daily Press Media Group, Newport News, VA, 2017) and *A Century at Langley: The Storied Legacy and Soaring Future of NASA Langley Research Center* (Joseph R. Chambers, NASA Special Publication 2017-07-101-LaRC, U.S. Government Printing Office, Washington, DC, 2017).

The seven AIAA members who were honored as part of the Hall of Honor's Class of 2017 are:

- AIAA Member Norman L. Crabill
- AIAA Honorary Fellow Dr. Smith J. DeFrance
- AIAA Associate Fellow Cornelius Driver
- AIAA Fellow Roy V. Harris
- AIAA Associate Fellow Harvey H. Hubbard
- AIAA Associate Fellow Edward C. Polhamus
- AIAA Fellow Dr. James H. Starnes Jr.

More information about the Hall of Honor can be found at: www.nasa.gov/feature/langley/naca-and-nasa-langley-hall-of-honor-class-of-2017.

National Capital Section Presents Future City Special Award

By Bruce Cranford

From 17 to 21 February, regional Future City winners from 44 middle schools nationwide, Canada, and China participated in the Future City National Finals in Washington, DC. Regional winning teams received an all-expense-paid trip to the National Finals.

Future City, in its 26th year, asks middle school students to create cities of the future, first on a computer and then in large tabletop models. This year's Future City theme was "The Age-Friendly City." Working in teams with a teacher and volunteer engineer mentor, students created their cities using the SimCity 3000 TM video game, donated to all participating schools by Electronic Arts, Inc. of Redwood City, CA. They wrote an abstract and an essay on using engineering to solve an important social issue, and then they presented and defended their cities before engineer judges at the competition. More than 40,000 students from more than 1,350 schools participated this school year.

The students created detailed—often fantastic—cities of tomorrow that give intriguing insight to how young minds envision their future. At the same time their bold designs and innovative concepts provide a refreshingly optimistic appreciation of how our nation can realistically deal with the many challenges facing its cities, including the power of public spaces.

As part of the Future City's program, the AIAA National Capital Section (NCS) presented a Special Award for the Best Use of Aerospace Technology to team Kenko Toshi (Team Members: Caroline Thomsen, Suzi Stegmann, Ella Spaulding, Evan Johns, Michael Chambers, Alex Gorman, Paige Wilson, Rylee Ford, Audrey Gemperle, Caitlin Boots, Faith Heacock-Johnes, Educator: Rexann Casteel, Mentor: Brad Stegmann, School: Gratton School, Future City Region: Northern California). The section congratulates the team for their outstanding efforts.

The Gratton School Future City Team

Photos by Future City

David Brandt, AIAA NCS chair, presented the award on 20 February. The award consisted of a savings bond for each student team member, and a plaque highlighting the award for each member of the team.

The section also wishes to thank the NCS judges for this award: David Brandt and Kevin Zezlina, Lockheed Martin, and Bruce Cranford, NCS Social Media chair. For more information and a list of all the winners, visit **www.futurecity.org**.

▲ Dr. Prakash Chand Jain (right) receives honor from Indian Union Minister of Science and Technology Dr. Harsh Vardhan (left)

Homi J. Bhabha Gold Medal Given To Dr. Jain

AIAA Associate Fellow **Dr. Prakash Chand Jain,** a scientist with Defence Research & Development Organization (DRDO) India, has been given the prestigious Homi J. Bhabha National Award by Indian Union Minister of Science and Technology Dr. Harsh Vardhan during the 105th Session of the Indian Science Congress. The award was given in recognition of Dr. Jain's significant contributions toward the development of science and technology, specifically in the realm of aerospace engineering. Dr Jain, an alumnus of the Indian Institute of Technology (IIT) Roorkee, IIT Bombay, and the Pennsylvania State University, specialized in the areas of aerospace structures technologies. He is a Fellow of Telangana Academy of Sciences and a Fellow of the Institution of Engineers India. In addition to various DRDO awards, Dr. Jain is the recipient of the coveted Dr. Biren Roy Space Science and Design Award from the Aeronautical Society of India.

The STEM of Planetary Exploration

By Andrew Neely

The K–12 STEM Outreach Committee would like to recognize outstanding STEM events in each section. Each month we will highlight an outstanding K–12 STEM activity; if your section would like to be featured, please contact Elishka Jepson (elishka.jepson@raytheon.com).

The STEM of Planetary Exploration coincided with the visit of Dr. Randii Wessen, mission architect from NASA Jet Propulsion Laboratory; he was visiting the AIAA Sydney Section with the AIAA Distinguished Lecturer Program. Schools and Girl Guides and Scout groups from all over Canberra were invited to nominate a small number of students to attend intensive, hands-on, interactive sessions. Held at the University of New South Wales (UNSW)Canberra, 65 children from 14 different Canberra area schools and a number of Girl Guide and Scout troops attended, as well as a large number of teachers, leaders and parents also attended.

The format for the day was based on the AIAA Sydney Section's successful *Science with an Astronaut* event from 2015. For this year, new activities were designed around the theme of a mission to Mars. The session began with a short presentation by Dr. Wessen about the design of planetary missions. The students were then split into small themed groups (Curiosity, Phobos, and ExoMars) to rotate through 3 hands-on activities each describing aspects of the mission: interplanetary travel, rover design, and rover teleoperation. For the interplanetary travel activity, students learned about the physics of trajectories and helped to design a Mars transfer trajectory using NASA's GMAT software by selecting and testing thruster burn times. They also learned about the economics of space flight and the promise of reusability before each attempting to land a SpaceX Falcon Heavy booster on a drone ship using VR goggles.

▲ Students in their subgroups design Mars rovers to ascend Olympus Mons.

In the second activity, they learned about the design considerations for planetary rovers and were tasked in groups with designing a rover to ascend Olympus Mons. In the final activity, they learned about the demands and limitations of teleoperation from orbit by remotely commanding, in task teams, an actual rover located 300 km away in the Mars Yard in the Powerhouse Museum in Sydney.

These activities were run by a large team of academics and Ph.D. students from UNSW Canberra and the University of Sydney. For a number of the undergraduate and postgraduate students and young professionals it was one of their first experiences delivering STEM K–12 outreach.

AIAA Greater Huntsville Section Volunteers at Galaxy of Lights

By Naveen Vetcha and Ken Philippart

On 6 December, visitors to the Huntsville Botanical Gardens (HBG) annual Galaxy of Lights found the AIAA Greater Huntsville Section staffing the ticket booths and directing traffic as they volunteered for the evening. Galaxy of Lights is a Huntsville holiday light extravaganza featuring larger-than-life animated light displays, which attracts over 30,000 walking night visitors and 25,000 carloads of people on driving nights. The event is HBG's largest fundraising event and is run almost exclusively by volunteers.

Section Chair Naveen Vetcha and the Council committed AIAA to helping on 6 December. Vetcha attended the training session as the event Day Captain and organized the section's participation. A call for volunteers was sent out and 29 AIAA members and family members signed up to help.

On the evening of 6 December, the AIAA Greater Huntsville Section banner was proudly displayed at the entrance to the Galaxy of Lights to let visitors know who was volunteering that evening. The volunteers worked for several hours collecting passes, selling admissions, directing traffic, and the night's proceeds, admitting 255 vehicles and collecting $1,400 to support HBG operations. AIAA Greater Huntsville's participation in the Galaxy of Lights was a fun and festive way for AIAA to give back to the Huntsville community during the season of giving.

▲ AIAA Greater Huntsville Section volunteers gather. The section thanks our volunteers: Naveen Vetcha, Brandon and Nicole Stiltner, Ken and Lisa Philippart, Tammy and Matt Statham, Richard and Karen Jozefiak, Thomas Barker, John Roy, Candice Dalton and her mom Melanie, Erin Gish, Brittani Searcy, her sister Bridget, her mom Jessica Huff and grandparents Bill and Joyce Huff, Eric Jackson, Tom Giel, Joe and Bobbey Huwaldt, Brenda Kimani, Carson Kennedy, Kurt Polzin and Mike Bangham.

Images courtesy of Naveen Vetcha and Lisa Philippart

Obituaries

Senior Member Fote Died in August 2017

Philip F. J. Fote, 84, and a 55-year member of the AIAA New England Section, passed away on 19 August 2017.

Phil Fote earned a B.S. in Aeronautical Engineering at Georgia Institute of Technology in 1957, and an M.S. in Physics at Northeastern University in 1961. Mr. Fote was employed at Textron Systems (formerly AVCO Corp.) in Wilmington, MA, for over 60 years.

Mr. Fote had extensive experience in the concept formulation, design, fabrication, and testing of missile weapon and commercial systems of all types. He performed analyses and directed other specialists in system and subsystem design of both domestic and foreign missile systems. The weapon systems extended from strategic missiles such as Minuteman and Peacekeeper to theater ballistic missile interceptors. The commercial reentry systems ranged from the Apollo Program to the current Orion Multi-Purpose Commercial Crew Vehicle Program.

Mr. Fote was a long-time member of the intelligence community. He had frequently participated in developing estimates of the design and performance of foreign missile systems and was a specialist in telemetry data analysis and critical technology identification.

As Chief Engineer, and previously Director of the Systems Concepts and Preliminary Design Department and Manager of the Aerothermal/Flight Dynamics Departments, he was responsible for the initiation and detailed design of weapon systems and various reentry concepts. Specializing in reentry physics, Mr. Fote led the transition from simple ballistic reentry shapes to the advanced designs of maneuvering vehicles. He was involved in the development, fabrication and testing of the AVCO reentry heatshield that was used to protect astronauts returning from the moon in the 1960s and 1970s.

Mr. Fote was more recently honored with a NASA award for his work on the Orion Multipurpose Crew Vehicle's heat shield, which flew on Exploration Flight Test 1 (EFT-1) in December 2014, successfully demonstrating the initial step toward protecting astronauts on future space missions providing safe reentry from beyond the moon and back.

AIAA Associate Fellow Oglevie Died in February

Ronald E. Oglevie died on 19 February at age 85.

Mr. Oglevie attended the University of California, Los Angeles, where he obtained his bachelor's degree in Mechanical Engineering. He later earned his M.S. degree in Aerospace Engineering at the University of Southern California.

During his career, Oglevie was a technical specialist in guidance, navigation, and control of space systems. He was involved in the Apollo, Space Station, Space Shuttle, and numerous satellite projects. After 34 years with Rockwell, he started his own business where he focused on Small Business Innovation Research contracts and consulting.

AIAA Fellow Schmit Died in March

Lucien A. Schmit, Jr., died on 16 March at age 89.

Mr. Schmit was widely recognized as the father of modern structural optimization (also known as structural synthesis). In 1960 he published a landmark paper introducing the idea of combining finite element structural analysis with nonlinear programming techniques. This basic idea led to the creation of a powerful new class of structural design optimization methods that have found use in major commercial computer programs used extensively in engineering practice. Many of the key ideas that advanced the state of the art in structural synthesis later provided useful guidelines for the development of multidisciplinary design optimization methods.

Before entering the academic world, Mr. Schmit was a structures engineer at the Grumman Aircraft Engineering Company (1951–1953) and later a research engineer at the MIT Aeroelastic and Structures Research Laboratory (1953–1958). In 1958 he joined the faculty of Case Institute of Technology as an assistant professor. He was advanced to associate professor in 1961, to professor in 1964, and in 1969 he was appointed Wilbert J. Austin Distinguished Professor of Engineering. Mr. Schmit was head of the Division of Solid Mechanics, Structures and Mechanical Design from 1966 to 1970.

In 1970, he was appointed professor of Engineering and Applied Science at the University of California, Los Angeles. From 1970 to 1993, he continued to teach and do research at the university, focusing special attention on creating efficient methods for large-scale, system-level, structural optimization. From 1976 to 1979 he was chair of the Mechanics and Structures Department.

An AIAA Fellow, Mr. Schmit was recognized with several awards including the AIAA Structures, Structural Dynamics, and Materials Award (1979), the AIAA Multidisciplinary Design Optimization Award (1994), and the Walter J. and Angeline H. Crichlow Trust Prize (1999) for pioneering seminal contributions to the initiation of structural optimization and multidisciplinary design and their evolution from abstract concepts to widely used practical tools.

1918

May 15 President Woodrow Wilson inaugurates the U.S. Air Mail Service in Washington, D.C. The mail is carried by seven single-engine Army Curtiss JN-4H Jenny biplanes between Washington and New York, but conditions are primitive. No aircraft radios exist and the pilots rely on landmarks to find their way. On Aug. 12, the post office takes over the service. By the end of 1925 there is a transcontinental route from Washington to San Francisco with a system of lighted airways that can deliver airmail in 29 hours, coast to coast. R.E.G. Davies, **Airlines of the United States Since 1914**, pp. 17-18, 27.

May 19 Maj. Raoul Lufbery of the 94th Aero Squadron of the U.S. Army Air Service dies when his Nieuport 28 is hit by German gunfire and set on fire during aerial combat. Lufbery chooses to jump to his death rather than go down in flames. He was one of the original members of the famous Lafayette Escadrille in 1916. David Baker, **Flight and Flying: A Chronology**, p. 112.

May 20 The Army reorganizes its aviation section and is no longer under the Signal Corps. There are two units, the Division of Military Aeronautics and the Bureau of Aircraft Production. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 8.

1943

May 1 Maj. Gen. Claire Chennault, commander of the 14th Army Air Force and organizer of the now-disbanded Flying Tigers corps of American volunteer pilots in China, receives the 1942 Gen. William E. Mitchell Memorial Award. The recognition is given to the U.S. citizen judged to have made the most outstanding individual contribution to aviation during the year. Chennault went to China in 1937 to train Chinese flyers; when the U.S. entered the war, he organized the Flying Tigers, who are credited with downing 300 Japanese planes before the group's dissolution in 1942. **Aero Digest**, May, p. 463.

May 11 The British BOAC airline starts passenger service between London and Lisbon, Portugal, using Douglas DC-3s. **Flight**, May 20, p. 53.

May 22 The Messerschmitt Me-262 turbojet fighter prototype is flight-tested at Rechlin, Germany. The test flights are lengthy, but successful, despite the 25-hour life of the aircraft's Jumo 004 engines. Series production does not start until spring 1944. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 45.

May 27 Edward Warner, vice chairman of the Civil Aeronautics Board, delivers the 31st Wilbur Wright Memorial Lecture before the Royal Aeronautical Society in London. Speaking on postwar air traffic, he predicts vast increases, both domestic and foreign, and says that foreign traffic may reach up to 600 transatlantic passengers daily. Warner also predicts that the London-New York route will take 15 hours. **U.S. Air Services**, June 1943, p. 20.

During May 1943

A U.S. Navy PBY Catalina airplane, fitted with two liquid-fuel jet-assisted-takeoff rockets developed at the Experimental Station at Annapolis, Maryland, takes off with a 20 percent reduction in the length of the run. However, the Navy abandons liquid-fuel JATOs in 1944 because of technical problems and because solid-fuel types are cheaper and easier to operate. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 45.

Capt. W.S. May of British Overseas Airways Corp. sets a record by crossing the Atlantic in six hours, 20 minutes, at an average speed of 506 kph. May flew a four-engine Liberator from Newfoundland, a distance of 3,540 kilometers. He was aided by a tail wind that sometimes approached 185 kph. **Flight**, May 6, p. 477.

Approximately 100 experimental A-4 rockets (later called the V-2) are test-fired from Blizna, Poland, by the German army; only a small number are successful. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 45.

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1968

May 2 The new Tanay Earth station near Manila, Philippines, helps inaugurate commercial satellite TV telecasts between Washington, D.C., and Manila through the Intelsat-2 F-2 satellite in geosynchronous orbit above the Pacific Ocean. **ComSatCorp Release 68-22**; NASA, **Astronautics and Aeronautics, 1968**, p. 103.

May 4 The Grumman Gulfstream 2 becomes the first corporate jet aircraft to fly nonstop from the U.S. to Europe when it arrives at London's Gatwick Airport after a 5,632-kilometer flight from Teterboro Airport, New Jersey. The aircraft is owned and operated by the National Distillers and Chemical Corp. **Flight International**, May 23, p. 783.

May 6 Astronaut Neil Armstrong is ejected from a Lunar Landing Research Vehicle, or LLRV, at an altitude of just 100 feet and parachutes to safety. He was attempting a simulated lunar landing at Ellington Air Force Base, Texas. The $2.5 million LLRV crashed and burned on impact. The cause of the accident is unknown. **Chicago Tribune**, May 7.

May 7 Bell Aerosystems Co.'s Wendell Moore, assistant chief engineer, and research associate Edward Ganczak are awarded U.S. Patent No. 3,381,917 for a type of jet pack, also called the Pogo, or Flying Chair. This invention is a continuation of Moore's pioneering work on jet packs that he has been undertaking since the 1950s. The inventors believe it will be useful for soldiers, policemen and firemen for quick missions, although the device fails to become successful commercially. **New York Times**, May 11, p. 45.

May 7 Juan Trippe, the founder, chairman and CEO of Pan American World Airways, also called Pan Am, retires after more than 40 years with the airline that he founded in October 1927. The company began with $300,000 in assets and a 145-kilometer route between Key West, Florida, and Havana. At the time of Trippe's retirement, Pan Am has $1 billion in assets and a route system of about 128,745 km. Najeeb Halaby succeeds Trippe as the president; Harold Gray becomes the chairman and CEO. **Aviation Week**, May 13, p. 42; **Flight International**, May 16, p. 743.

May 8 The European Space Research Organization launches its first two-stage Centaure rocket from Perdasdefogu, Italy, carrying a scientific payload from West Germany's Max Planck Institute up to an altitude of 88.5 km. **Washington Post**, May 9.

May 8 The first trans-Pacific satellite TV transmission of a visiting head of state to the U.S. to his home country occurs on the visit of Prime Minister Thanom Kittikachorn of Thailand to the White House. **ComSatCorp Release 68-24**; NASA, **Astronautics and Aeronautics, 1968**, p. 108.

May 12 Almost 20,000 attend the official dedication of Grissom Air Force Base in Indiana, named in honor of astronaut Virgil Grissom who died on Jan. 27, 1967, in an Apollo fire. The base was formerly called Bunker Hill Air Force Base. Grissom was born in Mitchell, Indiana. **New York Times**, May 13, p. 87.

May 13 Walter Haeussermann is chosen for a fellowship in the American Astronautical Society for "direct and significant contributions to the field of astronautics." The German-born Haeussermann is a pioneer in missile and rocket guidance systems and worked on the German V-2 missile guidance systems and flight simulations by means of analog computers. After the war, he came to the U.S. under Project Paperclip and came to head the development of the electrical, computer, guidance and navigation systems for the Saturn 5 for Project Apollo. Haeussermann became a U.S. citizen in 1954. **Marshall Space Flight Center Release 68-102**; NASA, **Astronautics and Aeronautics, 1968**, p. 111.

May 16 ESRO 2 reaches orbit on a NASA four-stage solid-propellant Scout booster. The spacecraft carries seven experiments for solar astronomy cosmic-ray studies representing six organizations from the United Kingdom, France and the Netherlands. **Washington Post**, May 17, p. D13; **Aviation Week**, May 27, p. 34.

May 18 NASA launches its Stratoscope 2 balloon-born telescope from the Scientific Balloon Flight Station at Palestine, Texas, to an altitude of 24,385 meters to photograph the sky from above 95 percent of Earth's atmosphere. The telescope was developed by Princeton University. **NASA Release 68-93**; NASA, **Astronautics and Aeronautics, 1968**, p. 116.

May 23 Echo 1, the world's first passive communications satellite, which was launched on Aug. 12, 1960, re-enters Earth's atmosphere and disintegrates over the southeastern Pacific. Echo 1 has also served geodesists to better determine accurate continental and intercontinental distances. **Washington Post**, May 24.

1993

May 25 The Magellan spacecraft is the first to use aerodynamic braking in entering the atmosphere of another planet when it enters the atmosphere of Venus to make gravity anomaly tests. **Spaceflight**, October 1993, pp. 358-359.

May 31 Scientists in Australia fly a prototype supersonic combustion ramjet for the first time. The scramjet shows promise as an efficient means of hypersonic propulsion for suborbital spacecraft. It is flown in a T4 shock tunnel. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 373; University of Queensland, **UQ News, July 22, 2002**.

SAMANTHA MCCUE, 28

Systems engineer and test director for Kratos Defense and Security Solutions' Mako unmanned aircraft


Kratos

Growing up in the Chicago suburbs, Samantha McCue and her siblings loved visiting their father at O'Hare International Airport where he worked in passenger and cargo services for airlines. McCue realized that aircraft were her calling. Now, as a systems engineer for the technical services company 5-D Systems, she works in Sacramento, California, at Kratos Defense and Security Solutions, a supplier of drones and aerial targets. She helped shepherd the jet-powered UTAP-22 Mako combat unmanned aircraft to flight testing. These Cessna-sized planes were designed from aerial target drones and can fly in formation with conventionally piloted warplanes. Once out of fuel, they fall to the ground under parachutes. In March, the U.S. State Department approved Makos for sale to European and Asia-Pacific nations.

How did you become an aerospace engineer?

When I was little, my siblings and I loved to visit our father at work and crawl around the cargo airplanes. From then, I associated airports and airplanes with adventure and discovery. My interests in aviation and spaceflight blossomed throughout school. At the University of Illinois, I earned a degree in aerospace engineering and a minor in the professional pilot program. I led teams participating in NASA test programs aboard the Zero Gravity Corp. "Vomit Comet" plane, interned with companies, earned my pilot's license, and advocated for STEM programs. After graduation I worked as a systems engineer on next-generation space capsules, gaining invaluable experience designing systems and their test programs. However, I wanted to get back to aviation, and particularly, work on unmanned systems. I started working on the Low-Cost Attritable Strike Demonstration program in 2016 as part of the Kratos team. About six months later, Kratos needed systems engineering support on the Unmanned Tactical Aerial Platform Mako program. In less than one year we integrated two new payloads, designed and tested a tablet control station for operators, modified the vehicle for land and water landing scenarios, completed multiple flight tests and participated in a full-scale military exercise. It's pretty hard to beat designing something in January and getting to flight test it in the summer.

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

In 2050, I think unmanned aircraft will be common for both commercial and military applications. Commercial unmanned systems will be better regulated and used safely in applications ranging from package and food delivery to providing infrastructure for communications in small, remote and/or depressed geographic areas. On the military side, I think we will see unmanned and manned systems teaming across all battle spaces: land, air and sea. Many tactical unmanned air systems like the Mako and Low-Cost Attritable Strike Demonstration will be flying with a few manned aircraft. Unmanned aircraft will be leading the missions and keeping pilots and their aircraft safe. It will be fun to reminisce about being an engineer at the beginning of the paradigm shift and know that I was a part of making that future a reality. ★

By Debra Werner | werner.debra@gmail.com