AEROSPACE
★ ★ ★ AMERICA ★ ★ ★

HOW TO BUILD A MEGA CONSTELLATION

Inside OneWeb's Florida factory, where the mission is to beat SpaceX to satellite internet PG 16

MARCH 2020 | A publication of the American Institute of Aeronautics and Astronautics | aerospaceamerica.aiaa.org

AIAA
SHAPING THE FUTURE OF AEROSPACE

A SpaceX booster touches down after launching 60 Starlink satellites in January. Sixty more were launched in February.

SpaceX

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AEROSPACE AMERICA

MARCH 2020, VOL. 58, NO. 3

EDITOR-IN-CHIEF
Ben Iannotta
beni@aiaa.org

ASSOCIATE EDITOR
Karen Small
karens@aiaa.org

STAFF REPORTER
Cat Hofacker
catherineh@aiaa.org

EDITOR, AIAA BULLETIN
Christine Williams
christinew@aiaa.org

CONTRIBUTING WRITERS
Keith Button, Christine Fisher, Adam Hadhazy, Robert van der Linden, Debra Werner, Frank H. Winter

John Langford **AIAA PRESIDENT**
Daniel L. Dumbacher **PUBLISHER**

ADVERTISING
advertising@aiaa.org

ART DIRECTION AND DESIGN
THOR Design Studio | thor.design

MANUFACTURING AND DISTRIBUTION
Association Vision | associationvision.com

LETTERS AND CORRESPONDENCE
Ben Iannotta, beni@aiaa.org

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.

AIAA SHAPING THE FUTURE OF AEROSPACE

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Keith Button

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

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Christine Fisher

Christine writes about technology, space and science. Her work can also be found on Engadget.com.

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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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Debra Werner

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

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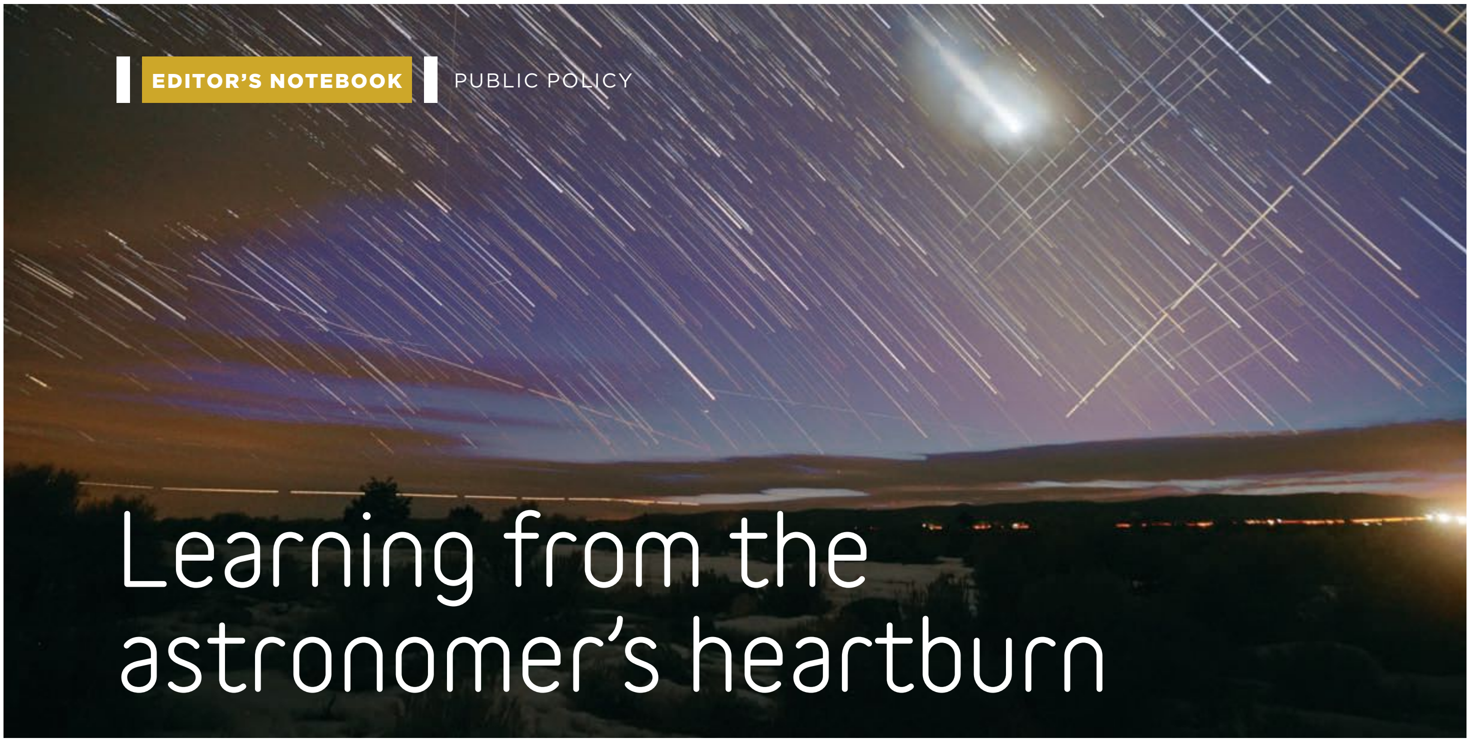
DEPARTMENTS



Learning from the astronomer's heartburn

▲ **The bright light of** Venus and the flares caused by Starlink satellites streak across the sky in a long exposure.
Mike Lewinski/Flickr

Space entrepreneurs and government managers around the world still have a chance to do something that hasn't been done well in the history of technology: Plan ahead.

At the moment, the tendency is to launch first and worry about the impacts on the space environment later. As yet there is no agreed-upon, mandated method for de-orbiting broken or worn-out satellites. No satisfactory space traffic management scheme is in place. No process for discovering issues like the glint from the SpaceX Starlink satellites that is disrupting astronomers' work.

Such oversights are unacceptable, given that the space environment doesn't belong to any single government, billionaire, corporation or profession.

The most telling aspect of the Starlink saga might be that the impacts on science were unanticipated. One has to wonder what other surprises lie ahead, given that the megaconstellations are just one innovation in a broad commercial revolution that's starting to unfold. Our future could be one of space factories, mining operations, scientific outposts and, in the boldest visions, human colonies. Space traffic management will be needed, along with optical communications, nuclear power and propulsion, artificial intelligence and more. These technologies could bring unintended consequences ranging from the annoying to the dire. Deconfliction seems like a must.

Given the stakes, the space-faring nations should establish a formal process for assessing commercial proposals for unforeseen risks and environmental impacts. Today, agencies and international organizations deconflict communications frequencies and assure launch safety, but no one is scouring proposals for the unknowns. Establishing a further-reaching review process would turn today's collection of space enterprises into a true space community.

If government agencies around the world think they can leave such matters entirely to the wisdom of the market, they should remember the deadly explosion of the Deepwater Horizon oil platform in the Gulf of Mexico. The ensuing oil leak quickly became a political liability for U.S. President Barack Obama. A decade later scientists continue to study the effects of the spilled oil on the ecosystem of the Gulf of Mexico.

Likewise, a cascading collision among satellites or other unforeseen complication could quickly become a political liability for governments around the world. Development of the space economy could be set back many years.

We need to learn from our history, whether it plays out in the Gulf of Mexico or an astronomer's telescope. ★

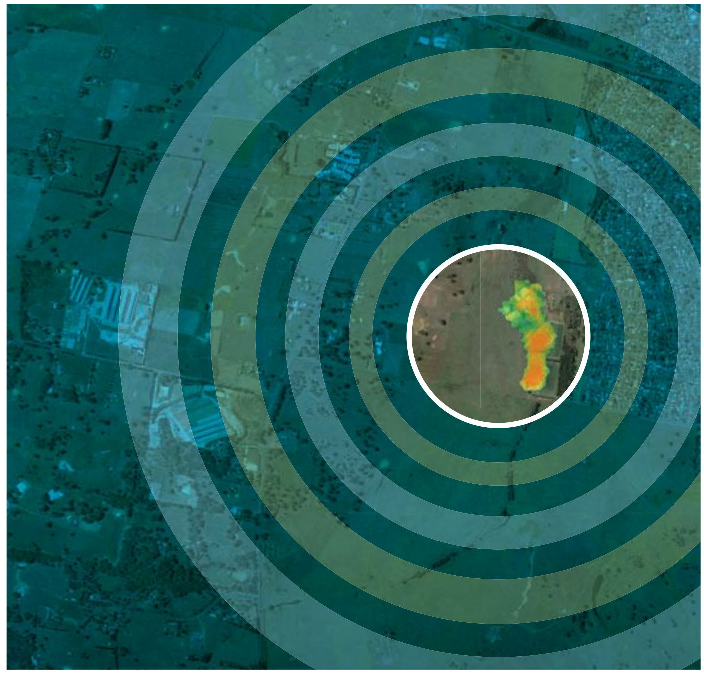
Ben Iannotta, editor-in-chief, beni@aiaa.org

CORRECTION

The article "Targeting methane" in the February issue incorrectly described the relationship between MethaneSAT and the Environmental Defense Fund. MethaneSAT is the independent nonprofit subsidiary created by the Environmental Defense Fund to build and operate the MethaneSAT spacecraft. The article also misidentified Ritesh Gautam. He is a senior physical scientist at MethaneSAT.

The sensitivity goal for MethaneSAT is to measure a 0.1% increase in methane concentrations in the column atmosphere, not at ground level.

Also, TROPOMI, short for TROPOspheric Monitoring Instrument, aboard the European Space Agency's Sentinel-5 Precursor, has a resolution of 7 km by 7 km.



FLIGHT PATH

Satellites: Driving A Burgeoning Space Economy

One of the biggest opportunities for economic growth on the planet actually begins 250 miles above it, where a developing space economy is building at speed. It's empowered by new business models, burgeoning partnerships, and technological advancements that are welcoming new entrants and fresh thinking to the space enterprise.

Space has long been home to thousands of satellites that provide crucial services for society. Most of this investment in space has been driven by national and military utility, such as communications; position, navigation and timing (PNT) systems; weather; and early warning systems. However, nearly all of these assets have dual use, and data and services have been made publicly or commercially available to help farmers maximize their crops, financial institutions process transactions, fishermen increase their haul, utility companies manage power grids, and more. The economic impact of these satellites cannot be understated.

Since the 1980s, GPS satellites have helped generate nearly $1.4 trillion in economic benefits. With roughly 8,950 satellites placed in orbit and more than 16,000 small satellites expected to launch by 2030, the importance of satellites in the economy will only increase. The majority of these activities have been funded by or in close collaboration with governments. With a new decade upon us, we see the space economy, led by innovative companies, new technologies, and novel business models, becoming commercialized and governments transitioning into enterprise customers.

A lot of progress has been made by innovators in the space industry who are building businesses with commercial business models. Leveraging investments from major technology companies in cloud computing, computer vision, and machine learning, space-enabled businesses are using these commoditized and open source technologies to build cost-effective products that deliver business value quickly. Applying these technologies and processes to remote sensing further decreases the barrier to entry for a non-remote sensing expert to extract insights within geospatial data.

By reducing the cost to reach space by a factor of 10 and developing satellites at 1,000x lower mass per unit performance and cost than 10 years ago, new commercial space companies—such as Planet, Spire and HawkEye 360—have made data that was once only accessible by government entities available to the masses. And it is being utilized daily across industries to achieve great things that were never imagined.

Meanwhile, the U.S. government is focused on advancing the capabilities of the space sector and relies on organizations such as The Aerospace Corporation to solve the hardest problems in space for both industry and government. This includes working to accelerate the speed of innovation and product development through an agile aerospace enterprise aimed at rapidly replacing space assets at speeds previously unprecedented, as well as developing new technologies, informing space policy, and aiding new entries into space.

These initiatives are already working. There has been an increase in medium-lift and heavy-lift launch vehicles offering piggyback launch opportunities for small satellites. The Indian PSLV and Russian Soyuz are much too expensive for most small satellite companies to purchase the full capacity of the rocket, but there's usually several hundred spare kilograms available on each flight—and Planet has already launched over 200 of its satellites as hitchhikers on bigger rockets. The launch side of the equation is also picking up with Rocket Lab launching six dedicated small satellites last year and SpaceX's announcement of a smallsat rideshare program, offering launch capacity as low as $5,000 per kilogram, an approximately 75 percent reduction in price from most options.

The growing support of government entities for the commercial enterprise sector has been particularly notable. Some governments and agencies are becoming enterprise customers and buying commercial subscription products, thereby incentivizing industry to build and deliver upgradable products. That means rethinking the way spacecraft are designed, built, and operated.

Satellites of the past were large, costly, and took a long time to test and build; they were also often in space for so many years that their technology became outdated. Small satellites are much less expensive and business models can incorporate rapid iteration of hardware and software. There's been continued support for companies that inspire evolution and growth following a classic market dynamics for disruptive innovation. Conferences such as Satellite 2020, Space Symposium, and GEOINT 2020 are critical to the development of these ideas and advancements.

Many individuals are in the space community because of the effect it has on the future of humanity. They have a desire to understand the cosmos, become a multiplanetary species, and devise ways to live more sustainable lifestyles. It is exciting to be a part of the Space Renaissance and the 21st century's rapidly-evolving aerospace ecosystem. New in 2020 is the ASCEND event, powered by AIAA, 16–18 November, where we will continue these and other discussions on the future of space, commercial dynamics, and societal needs. ★

Steve Isakowitz, Chief Executive Officer, The Aerospace Corporation
Robbie Schingler, Co-Founder & Chief Strategy Officer, Planet

AERO PUZZLER

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

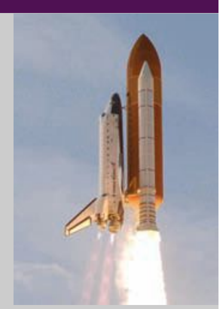
Climate impact

Q. Climate scientists are returning home after delivering a presentation about cirrus clouds. The pilot announces, “Ah, folks, we’re taking the shortest possible route from Washington Dulles to Vienna this afternoon, so sit back and relax, knowing we’ve done all we can to reduce this flight’s climate impact.” The scientists let out a collective groan. Why?

Draft a response of no more than 250 words and email it by midnight March 3 to aeropuzzler@aiaa.org for a chance to have it published in the April issue.

FROM THE FEBRUARY ISSUE

BURNING CLEAN



We asked you whether it’s true or false that water vapor would be the only emissions from the Space Shuttle Main Engines or a hypothetical hypersonic air-breathing vehicle fueled by liquid hydrogen.

WINNER: The statement as written is false. The shuttle main engines burn liquid oxygen, so as long as the hydrogen and oxygen are pure, the exhaust is water. But for the air- breathing vehicle, a large amount of nitrogen goes into the engine, and the heat will produce nitrogen oxides, which are a pollutant. There MIGHT be some other compounds created outside the shuttle engine itself, if the hot exhaust is enough to trigger some reactions in the surrounding air.

Bob Parks
San Jose, California
AIAA associate fellow
parky@mac.com

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

Meet the U.S. Army's new parachute

BY CHRISTINE FISHER | christine@cfisherwrites.com

Six years of design work and field trials have brought a successful conclusion to the U.S. Army's search for a better way to airdrop troops and heavy equipment into the field.

For 60 years, the conundrum has been this: The clusters of G-11 cargo parachutes that ease vehicles, ammunition and other supplies to the ground must be dropped from higher altitudes than the troops riding aboard the same plane or a nearby one. When troops are aboard, the cargo is pushed out the back of an aircraft such as a C-130, and then the pilot circles back at a lower altitude so the troops can ride to the ground under round steerable T-11 personnel parachutes.

Dividing the drops like this can be risky. "For forced entry capability, you want personnel and equipment on the ground at the same time, in the same pass, so you limit your exposure," says Ben Rooney, an engineer, who managed the project as part of the U.S. Army Product Manager Force Sustainment Systems, or PM FSS, an Army program in Natick, Massachusetts, tasked with providing equipment, systems and technical support for soldiers.

Several years ago, the Army awarded a contract to Zodiac Parachute and Protection America (now Safran Parachute & Protection America, the U.S. offshoot of the French aerospace giant) and Fox Parachute Services of Belleville, West Virginia, to design a new kind of chute, now designated the G-16.

If the engineers could make each chute in the cluster inflate faster, less altitude would be lost and heavy cargo could be released closer to the ground. This is done with a smaller parachute in the mouth of each to force the canopy open.

Soon the Army will be able to make tactical insertions with one plane, in one pass.

In field tests with the G-16 in 2017, the Army achieved a 25% to 32% decrease in minimum altitude required for cargo drops. The G-16 can drop loads up to 10 metric tons (22,000 pounds) with one to four parachutes from 230 meters above ground level and loads between 10 and 19 metric tons (22,001 and 42,000 pounds) with five to eight parachutes from 300 meters.

PM FSS is finalizing a sustainment contract, meaning the first parachutes will be in the hands of troops in 2021, Rooney says.

The G-16 is the same diameter as the G-11, about 9 kilograms lighter and packs in the same bag. "It's a true one-for-one replacement," Rooney says.

The design offers another benefit. Because the canopy is made of square, diamond and elliptical modules that are hand-tied together, not sewn like the G-11's long, triangular gores, it is easier to construct and repair. "The riggers can use their scissors or knife, and they can cut the ties, pull that module out, replace just the module and the canopy stays in service," Rooney says. ★

▲ **The G-16 cargo** parachute loses less altitude while deploying than its predecessor did, so it can drop cargo from lower altitudes. During testing at Fort Bragg, N.C., the load was a 130G motor grader weighing 16 metric tons.
U.S. Army

Jerry Grey

BY BEN IANNOTTA | beni@aiaa.org

Jerry Grey's obituary is in the AIAA Bulletin on **Page 59.**

Aerospace America was Jerry Grey's "baby," but in learning more about his professional life following his death last month, I now understand that this magazine was just one of several long-lasting professional passions for him.

For us, Grey was our founding publisher and editor emeritus. He led the launch of Aerospace America in 1984 as the successor to AIAA's Astronautics & Aeronautics magazine. When I joined the staff in 2013 as editor-in-chief, one of the first things I did was call Grey, who by then was retired and dividing his time between London and Florida.

His advice was to continue to capture the imaginations of not just specialists but also anyone fascinated by aerospace. Tone would be important, he said, but no relevant topic should be off-limits. Sometimes conventional thought had to be challenged. His profession deserved a magazine like that.

I hung up the phone ready to get to work.

This was classic Grey. "He emboldened me," recalls Elaine Camhi, my predecessor as editor-in-chief, who counted Grey as her mentor.

When Camhi became the magazine's top editor in 1991, she recalls running guest editorials in her first few issues. She did not have a science background, and she believed some thought it "iffy" to have a woman in charge. "Finally, Jerry said to me, 'You know, you're going to run out of friends soon.'" She asked Grey why anyone should care what she thinks. He said: "It's not that they care what Elaine Camhi thinks. They care about what the editor-in-chief of this magazine thinks."

Camhi began writing editorials.

"He gave me the courage to find — to tap into — my potential," Camhi adds. "He probably did that with a lot of his students," she says, referring to his decades as a professor at Princeton University in New Jersey.

One of those students was William Sirignano, now dean emeritus of the University of California, Irvine, who as a graduate student took a rocket propulsion course taught by Grey. "I always remember him as smiling, not frowning, even if he maybe wasn't happy with what I did," says Sirignano.

Grey was also renowned. When early versions of the engines for the Redstone and later Saturn launch vehicles exploded during testing, Grey was among those who researched the mystery. "As Tom Wolfe wrote, 'our rockets always blew up,'" Grey noted in a 2005 email interview with historian Tom Crouch of the Smithsonian National Air and Space Museum.

Grey and other researchers in 1960 proposed one explanation for this combustion instability: The natural frequencies in the combustion chamber were amplified by the size and shape of the combustion chamber, as well the design of the injector plate that directed the fuel and oxidizer into the chamber. Grey and colleagues called it the sensitive time-lag theory.

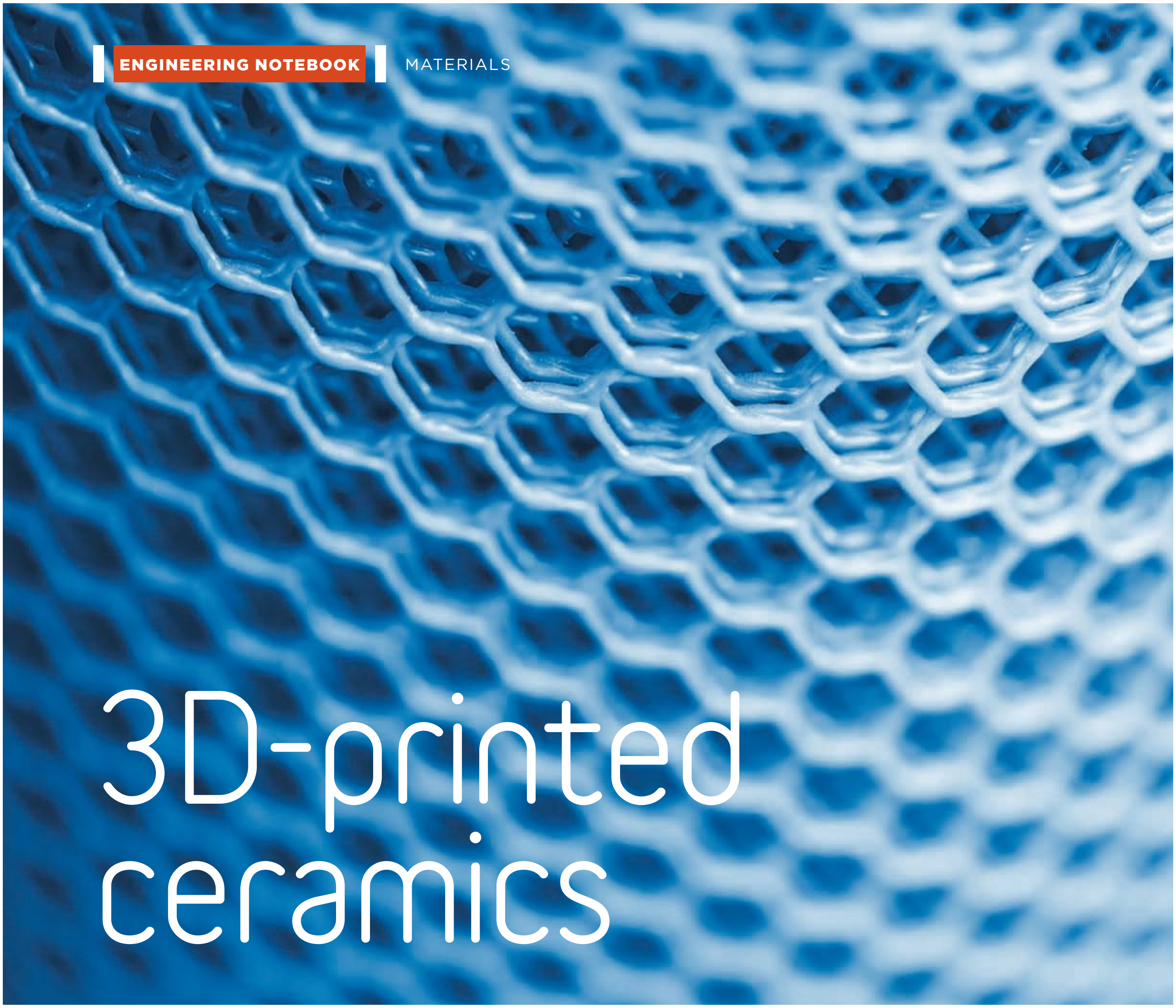
They went on to test this concept in a series of static engine fires at the Princeton laboratories. "We blasted dozens of copper rocket nozzles across the cattle-grazing fields adjoining Princeton's Forrestal Research Center," Grey told Crouch. This and other research led to changes in the F-1 engine in the mid-1960s, including enlarging the diameter of the fuel injector holes, Sirignano says.

By the 1990s, Grey had reached the status of elder statesman. In 1993, he shared his views on humanity's future in a New York Times profile, "Encounters: Where the Bay Meets the Sea, Thoughts of a Life in Space."

"Eventually I would like to think of the earth as a park-like place we could come back to visit from time to time," Grey said. "There will come a time when we will have no choice but to expand beyond the planet, if the human race is to survive."

Humanity "cannot stay still," he said. ★

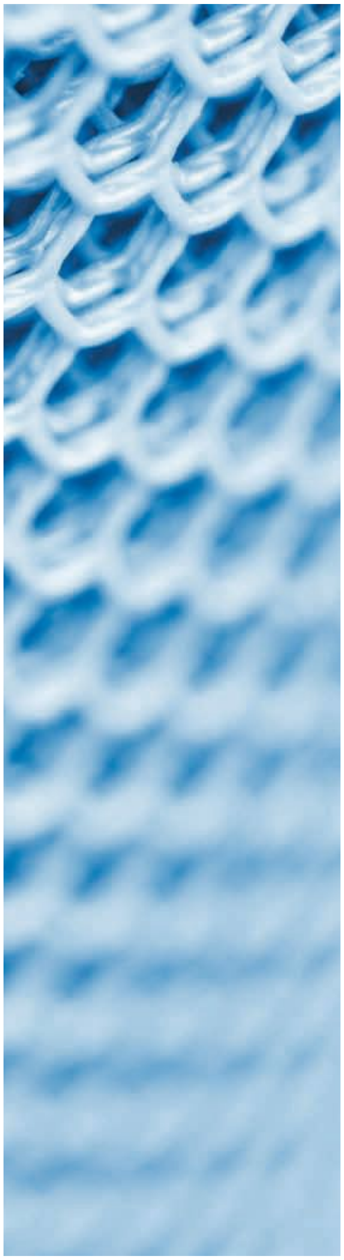
Staff reporter Cat Hofacker and associate editor Karen Small contributed to this report.



3D-printed ceramics

Making a single hypersonic weapon or space launch vehicle is one thing. Mass producing them is quite another. The strong, heat-resistant ceramic components they require are extremely difficult to produce. Keith Button spoke to materials scientists who think they have the solution.

BY KEITH BUTTON | buttonkeith@gmail.com



As aerospace engineers dream up new hypersonic weapons and space launch vehicles, they will need ceramic parts that can withstand temperatures as high as 2,700 degrees Celsius and drag forces of hundreds of kilograms that are encountered at speeds of Mach 5 and higher, such as on nose cones, wing leading edges and engine inlets.

The problem is: These ceramics are harder than titanium and brittle, making them tricky to work with.

To make a ceramic part, a technician typically presses a soft clay-like material into a die to create an approximation of the desired shape, hardens it in a furnace and then grinds it down to the precise shape. This milling process can take months and result in chipped or cracked parts.

Materials engineers and chemists at the U.S. Naval Research Laboratory in Washington, D.C., are developing a 3D-printing method that could produce the precise ceramic part shape with no milling required. Components could be made by any aerospace manufacturer with a particular kind of off-the-shelf commercial 3D printer, a paste of metal and polymer devised by the NRL scientists, and a furnace to cure the parts.

Early research

The idea of printing ceramic parts sprang from the NRL chemistry group's development, starting about 12 years ago, of a polymer resin powder that it mixed with various metal powders to make refractory carbides, which are a type of extremely heat-resistant ceramic. The NRL researchers made pellets from the polymer resin mixed with metals like silicon, titanium or tungsten, and then smushed the pellets with a hydraulic press and die into simple shapes. When they heated these pressed shapes in a furnace filled with argon gas at 1,500 degrees Celsius — like firing a clay pot — the polymer resin charred into carbon and reacted with the metals to form a ceramic.

The researchers investigated the 3D-printing idea because they wanted to apply their polymer-metal ceramics chemistry to more complex shapes than the discs, spheres and cones that they were making, explains Boris Dyatkin, a materials research engineer at the NRL. With the die-press method, the size and shape of the ceramic part is dictated by the die, and some shapes aren't possible with a die press. Also, "if you need to change the dimension of the part, or if you need to change a certain geometry aspect of it, it's more tricky to do it quickly," he says.

With 3D printing, "you're basically getting more customization in terms of what kind of a ceramic you can make," Dyatkin says.

Printer options

When the NRL researchers began to work in earnest on the 3D-printing concept, in 2018, they first had to decide which type of 3D printing was best. They considered lots of printer options. One possibility was fused deposition modeling. A printer head mounted on a robotic arm deposits beads of molten polymer that harden, layer upon layer, to form the object. Another candidate was powder-bed 3D printing. A laser melts specks of powder as layers of the powder are added to a box-like bed, and these specks harden together to create a structure. The shape is revealed by removing the loose powder. Or, alternatively, a printer head injects binding material into the powder to create the structure.

The researchers settled on a 3D-printing method called robocasting. They based this decision on the advice of NanoArmor, a California research and development company that pays the NRL to make the ceramics and test them for the Missile Defense Agency's hypersonic materials development program.

Normally, these robocasting printers make items ranging from pottery with intricate lattice structures to complex-shaped concrete panels for buildings. The printer's robotic arm moves a printer head that extrudes beads of paste that harden as they dry.

These printers were attractive, because robocasting can print larger structures than other 3D-printing methods, and it's cheap and simple. With virtually no training, "anybody could essentially print whatever they wanted to," says Tristan Butler, a materials chemist at the NRL.

Robocasting also opens possibilities for creating new ceramic composites. Manufacturers could add ground-up carbon fibers, in powder form, to the paste to make a carbon-fiber composite ceramic, Dyatkin says. Or, under two concepts the researchers haven't

Researchers at the U.S. Naval Research Laboratory are developing a method for making precise ceramic parts for hypersonic missiles and vehicles. These parts could be made by a 3D printer like this one.
3D Potter

explored yet: 1. A printer could extrude paste onto woven carbon-fiber mesh. Or, 2. Without a printer, the mesh could be dipped into a less viscous version of the paste or the liquidy paste could be poured into a mold containing the mesh. With both concepts, the combined mesh and paste would be fired in a furnace to create the composite ceramic.

Their big challenge was to make a paste that would be accepted by the printer and harden into parts that would be as dense as those they had made earlier. Generally, denser ceramics are stronger and more heat resistant.

They needed a binder to hold the mix together while dispersing the metal and resin molecules evenly throughout the paste.

The paste had to be liquid enough to flow through the printer head, but once extruded it couldn't be too damp or too dry. "There's kind of a delicate balance," Butler says. "You don't want it to dry too fast, because it will induce cracking. But you want it to dry quick enough that you can deposit multiple layers to build taller structures. It's something you have to dial in."

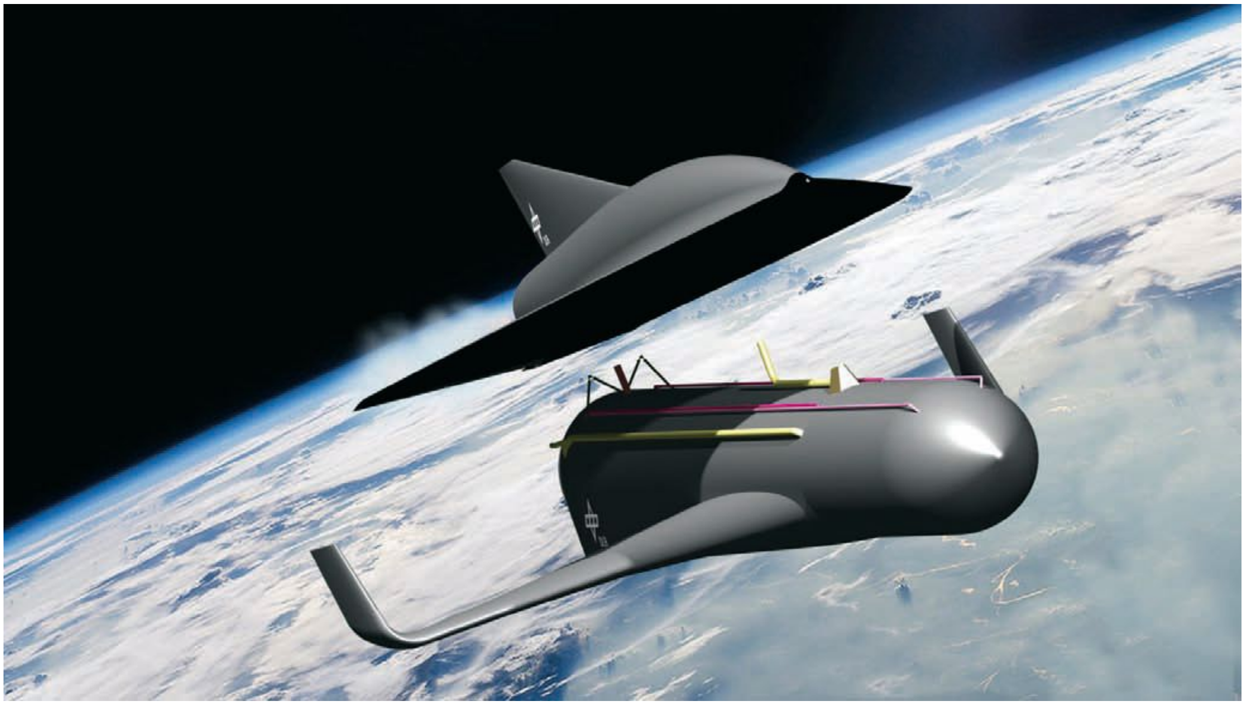
The key to achieving the right viscosity would be the choice of binder, which is a polymer and plasticizer that's mixed in powdered form with the powdered resin and metal. Liquid is added to create the paste. Once a part is printed, it's fired in a furnace to trigger the chemical reaction that turns the hardened paste into a ceramic, after burning off the binder.

The NRL researchers tried 10 to 15 binders common in 3D printing. Some were water-soluble and others alcohol-soluble. The scientists made pastes with each and created test discs. One of the water-soluble versions was chosen, because it proved best at creating a homogeneous mix of the right viscosity.

Researchers have 3D-printed hollow cylinders (shown) and tapered and conical discs several centimeters high as they refine their method.
U.S. Naval Research Laboratory

Looking ahead

At the moment, the shapes they've made by robocast printing are not as dense as those they've made with the die-pressed technique. The NRL researchers continue to search for the optimal heating rate for the furnace, meaning one that burns off the binder completely while fostering the resin and metal



SpaceLiner is a hypersonic passenger craft concept created by the German Aerospace Center. In this illustration, the SpaceLiner orbiter separates from its reusable booster stage.
German Aerospace Center

▲ **Other commercial** off-the-shelf 3D printers compatible with ceramics are made by Cerambot.
Cerambot

chemical bonds that must form to create a suitably dense ceramic. The researchers are also working toward printing objects — hollow cylinders and tapered and conical discs — that are taller and made from smaller beads of extruded paste, known as pixels in the industry. The smaller the pixels, the more precise and finely detailed the 3D-printed object can be. The NRL researchers are printing parts that are several centimeters tall made up of pixels that are just under a millimeter in diameter. They think eventually their printing method could produce parts as large as needed — building-size, in theory — of any shape. They haven't set a pixel size target yet.

Another goal: Figuring out how to create 3D-printed ceramics that are as close as possible to the density of die-pressed ceramics. To test hardness, they employ a microindentation tester. A small sample of the ceramic is placed on the device's platform, and a pin head measuring about 100-microns in diameter presses down on the surface to a preset pressure. The larger the microscopic indentation, the softer the material.

To assess how stable and strong the material will be when heated, they examine microscopic crystals in the ceramic with the help of an X-ray diffraction machine. A sample is placed on a pressure plate in the center of the machine; an X-ray tube shoots X-ray beams at the sample while a detector behind the sample rotates through a range of angles to pick up the reflected beams. The machine churns out graphs depicting the angles at which the X-rays are reflected by the crystals in the material and the intensity of the reflected X-rays. The various peaks in the graphs create signature patterns that software analyzes to identify the type and phase of metal or carbon crystals in the material, as well as size and volume of the crystals.

Another issue is that, so far, the 3D-printed ceramics have come out more porous than the pressed discs. In some cases, those microscopic gaps need to be filled to make the material denser and therefore stronger and more heat resistant. One option would be vapor infiltration. A gas in the furnace chemically reacts with the ceramic — either as it is forming or after it has formed — and fills in any pores. Another idea is to paint a solution on the 3D-printed object that would fill in the pores through a chemical reaction at lower temperatures, Butler says.

Even at this stage, the NRL researchers are thinking about how to make the process as easy as possible for aerospace manufacturers to adopt. The researchers sought advice from NanoArmor, whose executives have helped commercialize new materials and electronics technologies for several companies. Parts must be affordably mass produced, which means initial ingredients must be chosen with cost in mind. Efforts must be taken to eliminate any unnecessary steps.

"We pushed down requirements about scaling up, about costs, about timing," says Terrisa Duenas, NanoArmor chief executive. "A lot of times when you make a material, you don't even think about how to scale it up. And it just seems like: 'Well, we'll multiply by three or 10 or whatever you need,' but a lot of technologies don't scale like that." ★

HOW TO MAKE A MEGA CONSTELLATION

The race is on for satellite broadband as companies surge ahead with plans to blanket low-Earth orbit in satellites. The goal: provide global coverage while avoiding the pitfalls that led similar ventures in the 1990s to fail. Success will require each company to mass produce satellites. Cat Hofacker visited one of the firms leading the way.

BY CAT HOFACKER | catherineh@aiaa.org

It's a breezy January day along the Florida coast as I make my way through the winding roads not far from where the space shuttles launched. It dawns on me that the smartphone in my pocket is connected by cell towers and fiber to the internet, and I'm about to pull into the parking lot of a company that aims to seamlessly change how millions of smartphone users will access this vast repository.

I'm here at OneWeb Satellites, a joint venture of Airbus and communications company OneWeb, which is competing to bring satellite broadband to rural populations and someday perhaps even to places like Florida's Space Coast. OneWeb Satellites is mass producing satellites for the parent company.

The 240 technicians and engineers inside the Florida factory must churn out two 150-kilogram satellites a day to meet OneWeb's ambitious goal of erecting a constellation of 648 satellites in low-Earth orbit by 2021. If OneWeb or its satellite-broadband competitors succeed, then the bits and bytes of internet searches would course over a network of satellites and ground stations instead of fiber and cell towers.

▼ **An engineer prepares** to move a completed OneWeb satellite to a chamber to test for extreme temperatures.

OneWeb Satellites

OneWeb's furious production rate is driven by a need to expand the few dozen satellites it has in orbit before the market can be dominated by SpaceX's Starlink constellation or one envisioned by Ottawa-based Telesat. Retail behemoth Amazon also plans to be a contender in this market, but as of February it was still awaiting FCC approval for its megaconstellation.

Who is in the lead? As of February, OneWeb had launched 40 of its 648 satellites, and SpaceX had launched 300 of its planned initial constellation of 12,000. Telesat's were still on the drawing board.

Anyone around in the satellite business in the 1990s remembers the low-Earth orbit ventures conceived by telecommunications providers Globalstar, Iridium and others. Aspirations by Globalstar and Iridium to put blocky satellite phones into the hands of consumers were undercut by the terrestrial cell network builders, who rushed in with faster coverage at lower costs with cellphones from a variety of manufacturers, ultimately clearing the way for today's internet smartphones.

The competition facing the new LEOs is even fiercer, says Carissa Christensen, CEO of Virginia consulting firm Bryce Space and Technology. The

terrestrial providers are rushing ahead with plans to connect more remote areas via 5G, the fifth generation of networks for cellular mobile communications. If OneWeb and others are to have a chance at success, they must unlock the quick, affordable and reliable mass production that will help in deploying their constellations quickly.

“I as a business can control manufacturing,” Christensen says. “I can decide when I’m going to do it and how I’m going to do it and where I’m going to do it. I cannot in the same way control demand right there.”

▲ **One of the satellites** that will make up OneWeb’s internet constellation, in an illustration. The initial constellation will comprise 648 satellites in low-Earth orbit.

OneWeb Satellites

Design to manufacture

The custom-built Florida factory opened July 2019 and since then has been steadily increasing the number of satellites making their way along the assembly lines and into test chambers on the stark white production floor. This year, the technicians and engineers must build approximately 360 satellites to meet OneWeb’s high cadence of 10 launches of 30 to 36 satellites each for global coverage with the 648 satellites by 2021.

Fresh thinking was required to create the tooling and workflow for such a high rate of production.

“Traditionally, you build this complicated satellite and then you go on the floor and you ask the technician, ‘Hey, how can we improve this design to make it easier for you to build or work with?’” Joe Pellegrino, the launch campaign manager at OneWeb Satellites, tells me on the factory floor, where we’re both wearing slippers, hairnets and smocks. He previously built satellites at Boeing and Orbital ATK.

When OneWeb and Airbus joined forces in 2016 to build the Florida manufacturing plant, engineers and executives from both companies devised a new production model that emphasized speed.

“When they sat down and started designing these satellites, they kept manufacturing in their minds from the very beginning — making things easy to assemble, easy to troubleshoot, which is usually the opposite,” Pellegrino says.

The design of the factory flowed from that strategy. Satellites are built in two assembly lines, although these are not the continuously moving conveyor belts that the name implies. Each assembly line consists of “work cells” denoted by yellow tape: one for the propulsion module, another for avionics and a third for the communications payload module. Another cell is shared by both lines for the solar module.

“When they sat down and started designing these satellites, they kept manufacturing in their minds from the very beginning — making things easy to assemble, easy to troubleshoot, which is usually the opposite.”

— **Joe Pellegrino**, OneWeb Satellites

▲ **An automated guided** vehicle, or AGV, moves a OneWeb satellite around the Florida factory. The AGVs travel along red lines of tape laid down on the factory floor.

Ryan Ketterman

The process starts at one end of the factory, where parts for each module are grouped into kits and wheeled to the appropriate cell.

At the propulsion cell, technicians bolt Hall thrusters and a propellant tank onto a spacecraft panel and pressurize the tank with helium to prevent leaks, although later xenon will be loaded.

Over at avionics, other workers attach a sun sensor, star tracker and onboard computer to a panel. At the solar station, technicians assemble two solar arrays per satellite and deploy them in a preliminary test.

At the payload cell, they install a maze of wires and square tubes. Some are for the Ku-band antennas that will communicate with user terminals such as the small dome antennas that customers will affix to their roofs. Other equipment is for the Ka antennas that will connect to the ground stations, the entry points to the internet.

As each module is completed, a shiny boxlike robot rolls underneath it. These robots, called automated guidance vehicles or AGVs, whirl modules to the other end of the factory for final assembly, their cameras and navigation software following red lines of tape on the floor.

At the final assembly line, technicians attach all the panels together, except for the payload panel. Satellites then head to one of 32 test chambers. In these white, boxy structures, satellites "go through an abbreviated mission to make sure everything's working as expected," Pellegrino says.

Later, I sit down with CEO Tony Gingiss. He says the process is similar to auto manufacturing in that technicians work in one location for the most part during assembly. Traditionally, a satellite stays at a fixed spot in a clean room and "you bring all the equipment and all the operators to it" to install the solar panels, thrusters and so on, he says. "Ours is, you really move the equipment through the line."

The last step in the factory is loading up for launch. Technicians lift each spacecraft onto golden spring-loaded rails, which are then packed into 6-meter-long shipping containers. Two containers fill the back of an 18-wheeler parked right by the open door of the loading zone.

A large garage door slams shut, and that's it for the satellites I watched leave the factory. The next day, they were loaded onto an Antonov cargo plane and flown to Kazakhstan to a waiting Soyuz rocket.

"We believe we're at kind of a sweet spot in terms of the size and cost and complexity of the satellites that we're building."

— Erwin Hudson, Telesat LEO

They blasted into space in early February, pushed into orbit by the spring-loaded rails. Off they flew to reach their 1,200-kilometer orbits. This altitude, though still LEO, is higher than the 1,000 kilometers the Telesat satellites will occupy and the 550 kilometers used by the first phase of the Starlink constellation. The higher altitude means OneWeb needs fewer satellites for global coverage, though the fleet could grow to about 2,000 satellites if demand is high.

The satellites behind me on the assembly line won't be far behind those launched in February. OneWeb is planning to launch another batch of 34 in March.

Once the initial constellation of 648 satellites is in place, OneWeb the broadband internet provider will be open for business worldwide. Some customers, like schools in remote areas, would connect to the internet with the roof-mounted terminals. Other customers could buy a modem made by OneWeb or a OneWeb-approved supplier and receive internet via an existing provider such as Verizon or Comcast. OneWeb is also designing flat user terminals, resembling Wi-Fi modems, for aircraft and other transportation industries.

OneWeb Satellites has other customers in mind, too. Its co-owner Airbus Defense and Space is in the running to build satellite buses for DARPA's Blackjack program, a planned demonstration of 20 satellites in LEO to test alternatives to the Pentagon's geosynchronous missile warning or communications satellites.

The production line in place for the OneWeb satellites should translate well to making other spacecraft, Gingiss says, as long as customers "use it as it is."

He says you wouldn't walk into a General Motors factory and ask them to build an entirely different car.

"How much do you think that GM car's going to cost?" he says. "It's not going to cost $45,000 or $35,000; it'll cost millions of dollars."

That being said, the Florida production lines "could accommodate design variations," he adds. The company has a second factory in Toulouse, France, which means "lots of flexibility to whether we want to manufacture there, whether we want to manufacture on other days or shifts here [in Florida], whether we want to push everything to one production line here and use the second line for something else."

Change on the fly

The competition involves more than getting the satellites built right and into space. It's a battle of business plans, too. Unlike OneWeb, SpaceX wants to be a direct-to-consumer internet provider. Anyone could connect to the Starlink satellites via a user terminal that "looks like a thin, flat round UFO on a stick," founder Elon Musk detailed in a January tweet.

The terminals will send bits and bytes of users' internet searches to satellites via phased array antennas that track the satellites as they move across the sky, grabbing onto one after another to maintain an internet connection. Similar terminals exist today, installed on some aircraft and ships, but "such devices traditionally cost on the order of several thousands of dollars," says Tom Butash, who leads Innovative Aerospace Information Systems, his consulting firm in Virginia. Those prices could limit the number of users in the underserved communities to which Starlink is proposing to bring broadband access.

SpaceX is trying to drive down the price of the terminals, estimating they'll be around $200. Much more than that, Butash says, and that "relegates the service to enterprises or large organizations that can spread the cost over a large number of users."

Despite the uncertainty, SpaceX is charging ahead

▲ **Thirty-four OneWeb** satellites are shown on their dispenser atop a Soyuz rocket's Fregat upper stage at Baikonur in Kazakhstan.

OneWeb Satellites

▲ **A SpaceX Falcon 9** rocket carries the third batch of Starlink satellites in early January 2020 after launching from Cape Canaveral Air Force Station.

SpaceX

with Starlink, aiming for twice-monthly launches of 60 satellites each this year.

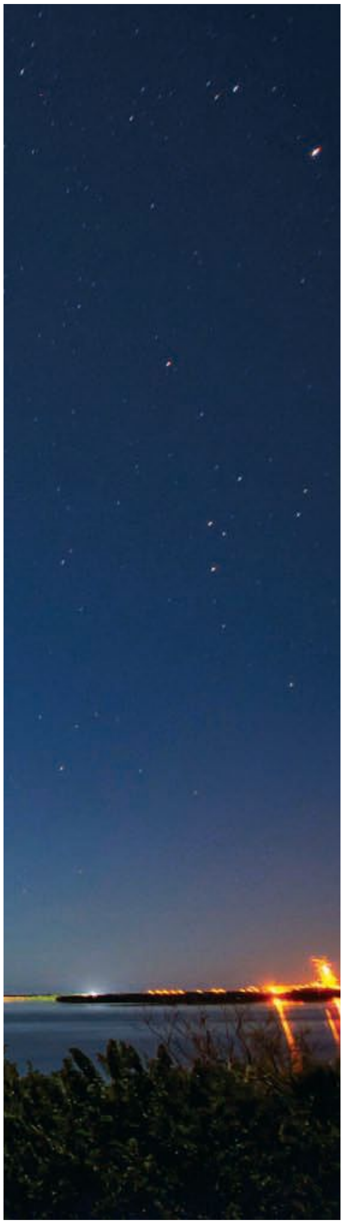
The company declined to discuss how it maintains that high production rate for the satellites, which are built in Redmond, Washington, but a press kit released last May before the first launch offers some clues. Instead of locking in the design as OneWeb has, SpaceX will continuously update future batches of satellites as necessary through a "rapid iteration" approach.

This is evident in the drastic difference between the two Starlink designs already unveiled. The two 400-kilogram test satellites launched in 2018, nicknamed TinTin A and TinTin B, had a cylindrical bus resembling a beer keg sandwiched between two bulky solar arrays, a stark contrast to the "flat-panel design" that debuted a year later for the initial constellation.

The updated satellites are about 227 kilograms with a rectangular bus and single solar panel that unfurls like a paper map upon deployment, a design that took "a couple months" to build, Musk told reporters during a May teleconference.

SpaceX in the press kit described the new look as one that was "significantly more scalable," a necessity if Starlink is to reach 12,000 satellites, as well as the additional 30,000 SpaceX asked the International Telecommunication Unit to arrange spectrum for in October. It's also easier to launch, with the flat-panel satellites stacking easily inside the nosecone of the Falcon 9 rocket like so many tabletops.

This approach, SpaceX suggests, could give it an advantage if further changes are necessary. The company is already testing an experimental darkening treatment on one of the satellites launched in early January after the May launch sparked reports of twinkling lines trailing across the night sky visible to the naked eye and complaints from astronomers about streaks of light left on their ground-based



telescope detectors.

The full impact of the megaconstellations on night sky observations is yet unknown. OneWeb Satellites' Gingiss told me in January that visibility to the naked eye is a "nonconcern" for OneWeb's satellites because of their smaller size and higher orbit than the Starlink spacecraft, but they could still mar telescope images. [Related story on Page 26.]

OneWeb says it has "taken the concerns from astronomers seriously," but would not say how design changes to alleviate those concerns might affect production. OneWeb and SpaceX are in the midst of ongoing discussions with astronomers about the impact of their megaconstellations.

Slow and steady

Unlike OneWeb and SpaceX, Ottawa-based operator Telesat plans to outsource its manufacturing. In a few months, the company will choose among Airbus Defense and Space, Maxar Technologies in Colorado and Thales Alenia Space in France to manufacture an initial constellation of 292 satellites the size of small pickup trucks to beam broadband to traveling aircraft, ships at sea and other business customers.

"We believe we're at kind of a sweet spot in terms of the size and cost and complexity of the satellites that we're building," says Erwin Hudson, vice president of Telesat LEO, who's overseeing the constellation's development.

Telesat and the contractor teams have spent the last two years developing and testing the "key building blocks" of the satellite, Hudson says, in hopes of streamlining mass production once it begins later this year. For example, apertures on the phased array antennas that send and receive signals between the satellites and user terminals will be 3D-printed, turning "what would have been hundreds of parts into one single part number," Hudson says.

Robots will help human technicians in assembling the satellites, but Hudson stresses that "we're not trying to replace [humans]; we're just trying to get things done quicker, more reliably, more consistently."

Along with broadband coverage, Telesat envisions another big market for the LEO constellation is helping send traffic over the forthcoming 5G networks, an option OneWeb is also considering. The thinking is that telecom operators will need satellites for backhaul, connecting remote towers or base stations to the core communications network.

High cellular traffic could require more satellites than the initial 292 to handle backhaul, and Hudson says the manufacturing for Telesat LEO could be easily increased to meet that demand. "We can scale up in increments, and there's different increments, but we've got some predefined ways: We can scale up to 500, we can scale up toward 1,000."

Even with its 2022 entry-to-service date, Telesat is not the slowest-moving company in the market. Amazon last year announced plans for a 3,236-satellite constellation called Project Kuiper that when fully deployed "will provide continuous coverage of the United States and its territories, with the exception of Alaska," according to a technical analysis submitted with the FCC application.

Details on the timeline for Project Kuiper are scarce, with an Amazon spokesman noting only that "this is a long-term project that will take years to roll out." According to the FCC application, the constellation can begin "commercial operations" after the first 578 satellites are launched.

"The goal here is broadband everywhere," Amazon founder Jeff Bezos said last June during the company's re:MARS conference in Las Vegas.

As far as production, the company opened an approximately 20,000-square-meter facility in Redmond, Washington, last December for research and development. Satellite prototypes will eventually be manufactured there, but the spokesman declined to say if Amazon will build the actual satellites for Kuiper in-house or select an outside manufacturer.

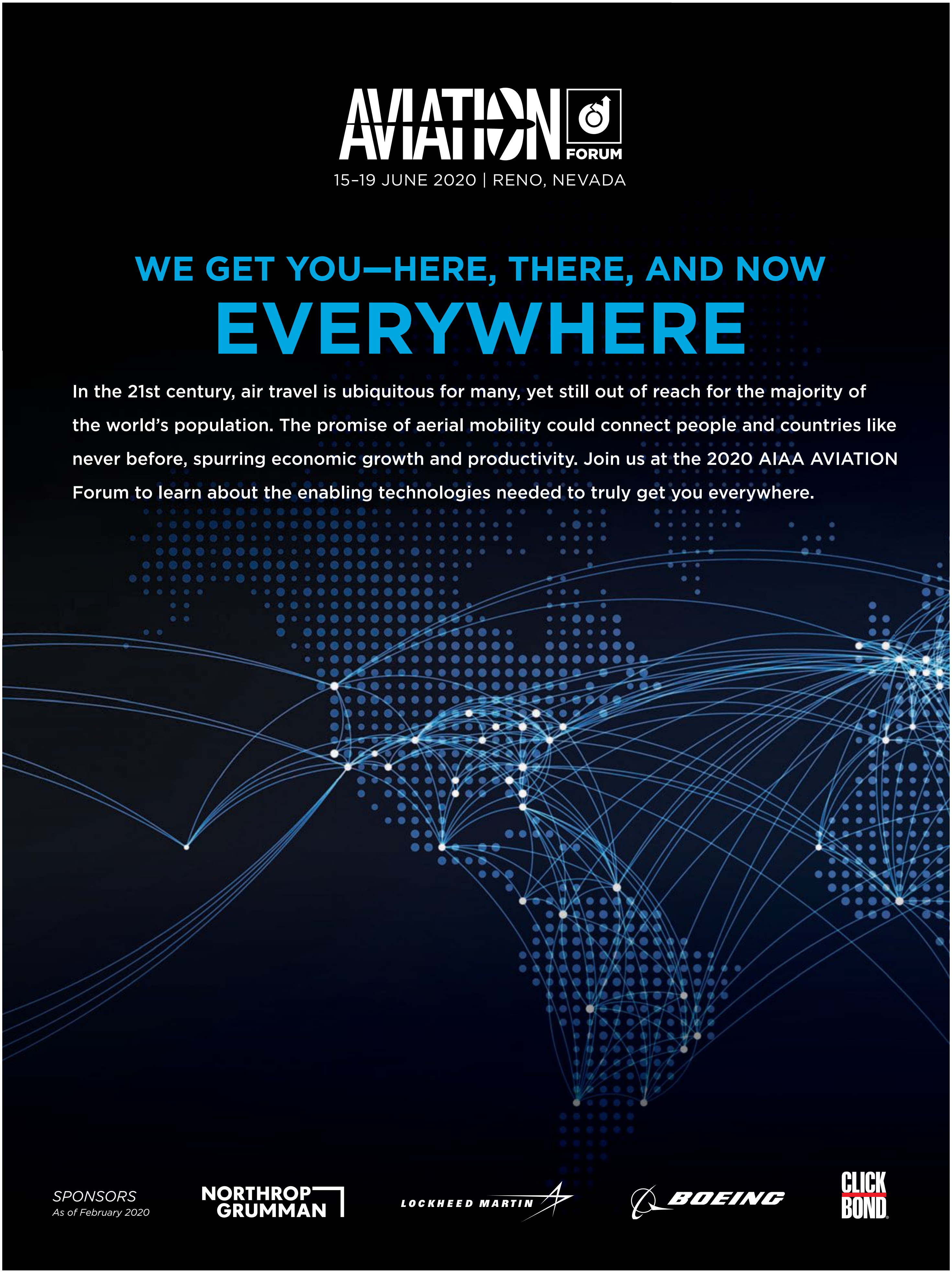
Breaking into the market

No matter their specific plans, each company sees a large market for its constellations. Amazon estimates that Kuiper will serve "tens of millions of people" currently without broadband access, and SpaceX President and COO Gwynne Shotwell said in February that Starlink "is an element of the business that we are likely to spin out and go public." Industry analysts aren't as optimistic, given that terrestrial providers such as Verizon and AT&T have expanded their coverage areas since forcing Iridium and Globalstar to emerge from bankruptcy in the mid-2000s with drastically revised business plans.

OneWeb and its competitors "believe they can make [the constellations] profitable, but my belief is if you look at the expanse of their coverage area, you see increasing areas of the world that are covered by 3, 4, and now 5G broadband wireless," says Virginia consultant Butash. "If you include fiber and cable, the area of lost satellite broadband demand is even greater."

Asked about the race against terrestrial services and other LEOs, OneWeb Satellites' Gingiss admits "we have a challenge here," but he's confident in the production model his company has built.

"I think there are a lot of people who are going to be able to leverage what we have at a price point and a schedule point and a quality point to do missions that they could have never dreamed of doing," he says. "Because for the price of what was maybe one or two satellites before, they'll be able to launch a whole constellation of satellites." ★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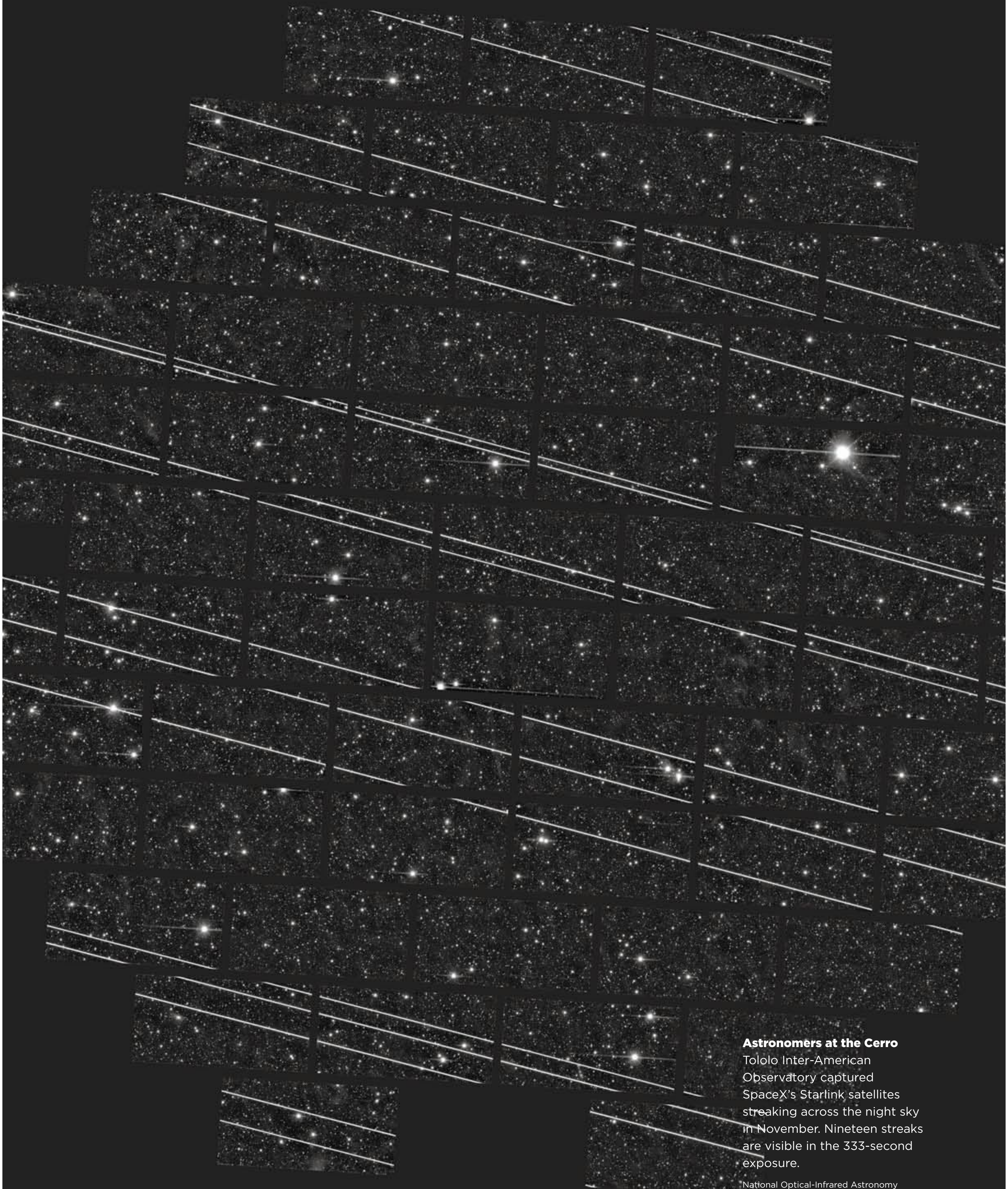


Astronomers at the Cerro Tololo Inter-American Observatory captured SpaceX's Starlink satellites streaking across the night sky in November. Nineteen streaks are visible in the 333-second exposure.

National Optical-Infrared Astronomy Research Laboratory/CTIO

MEGACONSTELLATIONS, MEGA TROUBLE

Sending hundreds or thousands of satellites into low-Earth orbit looked like a harmless and lucrative way to target broadband internet services to societies that lack them. Then came the first launches by megaconstellation pioneer SpaceX. Adam Hadhazy assesses the surprising collateral damage to astronomy and what might be done about it.

BY ADAM HADHAZY | adamhadhazy@gmail.com

Like other observational astronomers, Cliff Johnson has shrugged off those rare times when a photobombing satellite has ruined a telescopic image. Johnson could not so easily dismiss what he saw in the wee hours of Nov. 18, 2019. In a room at Fermilab outside Chicago, Johnson had just received real-time observations from a mountaintop telescope in Chile some 8,000 kilometers away. Numerous bright, parallel lines of light sullied the expected pristine views of the Magellanic Cloud galaxies. "Nineteen streaks across a single exposure is pretty incredible," says Johnson, a postdoctoral fellow at Northwestern University. "That's got to be some kind of record."

Johnson was describing his encounter with a batch of 60 Starlink satellites launched just a week earlier by Elon Musk's SpaceX company. Over the course of five Starlink launches since last May, casual observers have reported the streaks as UFOs and astronomers have challenged satellite engineers to help identify technical solutions to a threat to their science.

Astronomers count on long exposure times to gather the rare, valuable photons that have reached Earth from distances of millions of kilometers for solar system objects to quadrillions of kilometers for galaxies beyond our own. During these exposures, light reflected by satellites can saturate telescope picture elements, rendering these pixels useless for astronomical observations. The resulting streaks of light can mar or hide faint objects of interest or stand in as bogus data. Adding to the problem, "ghost" light can linger in the saturated pixel well past the time an offending satellite has passed out of view, affecting later observations and overall jeopardizing a significant percentage of a night's observing time.

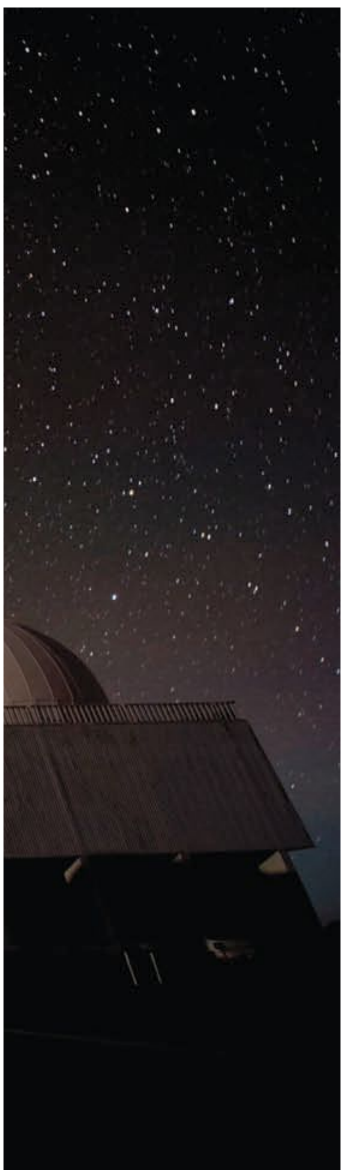
"Even if it's just a few percent [of telescope observations] lost, that could be the difference between

▼ **The Dark Energy** Camera at the Cerro Tololo Inter-American Observatory captured the images of Starlink satellites.

Fermilab

“EVEN IF IT’S JUST A FEW PERCENT [OF TELESCOPE OBSERVATIONS] LOST, THAT COULD BE THE DIFFERENCE BETWEEN GETTING YOUR SCIENCE OR NOT.”

— Cliff Johnson, Northwestern University



getting your science or not,” Johnson says.

Astronomers are bracing for the problem to get worse as SpaceX and its competitors race to loft megaconstellations of hundreds or thousands of satellites. A mere fraction of the total number of proposed satellites has been launched thus far, and astronomers worry that some might reflect light as the current Starlink satellites do. All in all, the planned activity represents a dramatic rise from the 1,500 or so satellites currently occupying low-Earth orbit. It’s all part of a gold rush of sorts to sell broadband internet connections to an estimated 3 billion people who have never had them.

Low-Earth orbit — which arbitrarily extends to 2,000 kilometers (1,200 miles) — is an attractive destination for these constellations, because LEO satellites orbit at least 18 times closer to internet users than geostationary satellites, depending on the precise orbit chosen. Bits and bytes won’t need to travel as far, which means websites and search results will load faster. But for astronomers, low altitude also means that significant sunlight could be bounced toward the Earth from the satellite bus, which is typically made of metal alloys, as well as the satellite’s large, flat solar panels and smack dab onto telescopes’ mirrors.

Starlinks’ light pollution caught astronomers by surprise. “Until we saw the first 120 satellites go up, this was not in the forefront of people’s minds,” says Johnson, referring to SpaceX’s hackle-raising first two launches.

The scale of the potential change in the night sky is profound, both for astronomers and casual observers. Prior to the Starlink launches, there were about 200 objects in Earth’s orbit visible to the naked eye, says Patrick Seitzer, an astronomer at the University of Michigan and a member of a committee convened by the American Astronomical Society in Washington, D.C., to consult with SpaceX and rival OneWeb about the impact of their constellations. Visible satellites can be a problem for astronomers, but long exposure times mean that even objects that can't be seen by the naked eye can be an issue. The problem is about to get a lot worse. With five Starlink launches in the books as of February, and at 60 satellites a pop, the total has more than doubled, and if the schedule holds, the total will skyrocket to nearly 1,600 objects by the end of 2020. The brightness of the satellites diminishes as they ascend to their operational orbits, making them less of a problem for astronomers, while naked-eye sightings continue. The luminous train Johnson witnessed were Starlinks that had just been released at a low altitude of 290 kilometers. Once cleared for service by SpaceX, they will ascend to their operational altitudes of at least 500 kilometers. Also, satellites aren’t visible in the night sky unless they are at an altitude that keeps them outside of the cone of Earth’s shadow and they are reflecting toward Earth. This is why satellites catch a lot of sunbeams in the hours after the sun sets and before it rises — so much so that the orbiting machines could shine brighter than all but 170 or so stars in the night sky, according to a recent paper by Italian astronomers.

“If the LEO sat operators fail to darken their satellites, the sky is going to be forever different. It will be swarming,” says Anthony Tyson, an astronomer at the University of California, Davis.

Pushing back — gently

As their starting point, astronomers suspect that few authorities would choose the night sky over the gains in education, health care and economic opportunity that could come with the internet.

“People believe now that internet access is a human right, like food and water,” says Whitney Lohmeyer, an assistant professor at the Olin College of Engineering and a former engineer at OneWeb, the London and Virginia company that plans to erect an initial constellation of 648 internet satellites.

Also, the sunk costs in the megaconstellations are enormous. SpaceX has publicly estimated the cost of establishing its decadelong Starlink constellation at $10 billion.

As for legal recourse, even if there were a passage in international space law that could be seized, the pace of satellite launches by SpaceX, OneWeb and

The leaders

These four companies are farthest along in developing megaconstellations.

COMPANY	CONSTELLATION NAME	INITIAL CONSTELLATION SIZE	GROWTH PLAN	FIRST LAUNCH	NUMBER IN ORBIT AS OF FEBRUARY	ALTITUDES
OneWeb Florida and France	OneWeb	648	1,980	February 2019	40	1,200 kilometers
Telesat Canada	Telesat LEO	292	512	July-September 2021	0	1,000 km
Amazon Seattle	Kuiper	578	3,236	Unannounced	0	590, 610 and 630 km
SpaceX California	Starlink	12,000	42,000	May 2019	300	340, 550 and 1,150 km

SOURCE: AEROSPACE AMERICA RESEARCH

soon others mean that any outcome in the astronomer's favor would likely come too late.

So, the astronomers have chosen to appeal to the megaconstellation operators to be good stewards of the sky.

The strategy might be working. A search has begun for solutions.

Collaborating

Since after the first Starlink launch, last May, Tyson has had a team working with SpaceX on identifying ways to implement a satellite-darkening technique, the first trial satellite of which launched with the third Starlink batch in January 2020. "If we can darken these things by a factor of 100, that should be sufficient," he cautions. More realistic might be 10-20 times darker, which "would allow us to mitigate most of the science impact via massively increased data processing as well as data analysis challenges that the science community will have to deal with," Tysons says.

As astronomers go, no one has more to lose than him. He is chief scientist for the Vera C. Rubin Observatory (formerly the Large Synoptic Survey Telescope) that's being constructed in the foothills of the Andes Mountains in Chile. When the observatory begins operating in 2022, its telescope will feed light to the biggest digital camera ever constructed, creating movies of the entire sky every three nights. Anything and everything that shines will be captured, including potentially unknown, short-lived astrophysical phenomena.

"WE ACTUALLY STEER THE SATELLITE THROUGH ITS ORBIT IN SUCH A WAY THAT TRIES TO KEEP ALL THE REFLECTIVE SURFACES EITHER POINTED TO THE SUN, OR POINTED IN A WAY SUCH THAT ANY GLINT FROM THE SUN WOULD GET REFLECTED OUT INTO SPACE AND NOT DOWN TO THE EARTH."

— Erwin Hudson, Telesat

The observatory's designers were braced for some satellite streaking, but they figured they could cope with it through image processing, when necessary. Then with the rise of Starlink, a shock came when the astronomers began running simulations. The ballpark results for a full constellation of 12,000 Starlink satellites suggested that 200 of them would be visible to the telescope at any given time. Not every satellite would necessarily show up on the Rubin's camera, depending upon the season and the time of night and thus the amount of potential sunlight that could be reflected back down to Earth. But still, likely a few tens of percent of images would be affected, with their data potentially spoiled. If SpaceX decided to expand its constellation to its upward limit of 42,000 satellites, and other companies launched their own megaconstellations, Tyson says estimates suggest upward of 70% of the Rubin's observations would be lost.

One reason the satellite streaks would be so damaging is because they could masquerade as luminous arcs naturally created by foreground galactic clusters when their gravity bends and magnifies the light of farther-off clusters. Cataloging these arcs allows scientists to gauge the amounts of invisible dark matter in galaxy clusters, because dark matter's mass contributes to the overall lensing effect. Studying the distribution of dark matter in this way is also a fundamental tool for measuring the effects of dark energy, an even more baffling entity that seems to be accelerating the universe's rate of expansion over the course of cosmic history. Perhaps more pertinently for non-astronomy enthusiasts, droves of satellites would also make it difficult to spot sizable, city-killer asteroids that could someday collide with Earth, and which are best viewed during the so-called astronomical twilight, after the sun sets and before it rises, exactly when satellites would be brightest, too.

The SpaceX darkening technology could sharply reduce reflectance on certain Earth-facing places on the satellite bus. Per a nondisclosure agreement, Tyson cannot say more than that. SpaceX declined an interview request, pointing instead to past statements that the company is now working with astronomers.

One thing Tyson can say is that SpaceX is going beyond the conventional technique of painting a satellite black with a polyurethane called Aeroglaze Z306. This method leaves a flat black finish that still reflects about 3.5% of incident light.

A perhaps ideal solution, in terms of exquisite darkness with near-zero reflectivity, would be carbon nanotubes. "That's glorious stuff," Tyson says. The problem is, carbon nanotube coatings are fragile. They flake right off from basic handling and would likely be damaged in the faring during launch and deployment. "I don't think we can use that stuff on satellites," says Tyson, "but I may be wrong."

▼ **Installation of the** structure that will hold the telescope at the Vera C. Rubin Observatory being built in Cerro Pachon, Chile.

Vera C. Rubin Observatory

Not dark, but smart

Of course, darkening agents can't be applied to solar arrays.

To cope with the glint from these components, the Ottawa-based company Telesat has drawn a lesson from the 66-satellite Iridium constellation completed in 1998, which was the megaconstellation of its day.

These satellites famously generated brief flashes, dubbed Iridium flares, when sunlight struck their solar arrays or their door-sized antennas at certain times of night.

Iridium flares turn out to be avoidable, says Erwin Hudson, a vice president at Ottawa-based Telesat who is in charge of rolling out the company's proposed network. "We orient the satellites in orbit so that the solar panels, which are the biggest, flattest surface on the spacecraft, are always pointed to the sun," says Hudson. "And we actually steer the satellite through its orbit in such a way that tries to keep all the reflective surfaces either pointed to the sun, or pointed in a way such that any glint from the sun would get reflected out into space and not down to the Earth."

Hudson says his companies and others are, in fact, trying to be good stewards of the night sky.

"The whole industry is very aware that we need to protect optical astronomy, we need to protect radio astronomy, and we need to do all the other things that it takes so that we can all share this resource of orbits and spectrum," Hudson says. "We have built in all these good-citizen features from the very beginning of our design."

OneWeb, meanwhile, has just begun its launch campaign, having deployed 34 satellites in February after an initial launch in 2019 of six satellites that the company says are performing well. As of press time, this deployment had not triggered the kind of naked-eye sightings and telescope photobombings around the world as Starlink's had. Compared to SpaceX's Starlink, OneWeb believes its smaller satellite sizes, far lower overall constellation numbers, and higher orbital altitudes will be less of a problem to ground-based astronomy. A key enabler for this potentially less-impactful megaconstellation architecture is that the company has secured advantageous radio spectrum rights, permitting transmission on higher, more-data-loaded frequencies. More data per unit of time translates to fast-enough internet speeds, even when placing fewer satellites in higher orbits, closer to what is termed medium-Earth orbit, or MEO. "Our satellites are higher altitude, so their visual footprint is far reduced," says Dylan Browne, OneWeb's president of government, business aviation and maritime. Other operators, without rights to premium portions of the

▲ **This 1.5-meter-diameter** lens will be part of the biggest digital camera ever built, which will be installed at the Vera C. Rubin Observatory under construction in Chile. Astronomers are worried that megaconstellations of communications satellites will harm the camera's products.

Farrin Abbott/SLAC National Accelerator Laboratory spectrum, have to deploy significantly more satellites at lower altitudes to achieve acceptable latency, Browne explains.

Over the longer term of megaconstellation operations, a related, additional concern is the fate of satellites that malfunction and lose any ability to adjust their own orbits through thruster firings, or simply grow old and reach the end of their operational lives. Such defunct satellites would pose collision risks to active satellites, as well as each other, plus contribute to astronomically obstructed views, especially should their orbits decay. To address this problem, OneWeb's satellites each will have a so-called grappling fixture. The fixture — a small projection on one side of the satellite bus — is studded with a hodgepodge of means for other spacecraft to grab on for retrieval or deorbiting purposes. The methods of connection run the gamut from mechanical — like with a robotic arm — to magnetic, adhesive and even penetrating capture techniques. Still other mitigation methods, such as steering satellites clear of observatories during sensitive viewing periods, could well work for traditional observatories with set schedules for when and where they are pointed in the sky. Not so, however, for the Rubin Observatory and other wide-field, long-exposure projects. Nor does Tyson think image processing software, albeit ever-improving, will be able to plausibly handle the extreme load if indeed tens of thousands of satellites soon occupy the heavens.

The only way forward, then, will be to make the satellites disappear into the black of space as much as possible. "We find that SpaceX is committed to darkening their satellites," Tyson says. "If SpaceX somehow finds a way of darkening the satellites sufficiently, I feel that will rub off on the other" megaconstellation operators.

With the pace of satellite launches accelerating this year, the astronomical community has put operators on alert, with statements and public engagement. Prominent professional groups besides the American Astronomical Society have expressed their concern, including the Association of Universities for Research in Astronomy, a consortium of universities and other institutions that manages major telescopes on behalf of the National Science Foundation and NASA, along with the International Astronomical Union, a globe-spanning organization of 13,500 professional astronomers hailing from over 100 countries.

Says Tyson: "I don't think we should sit back and wait for someone to save our day." He pauses. "Or our night." ★

▼ **When Iridium** launched its constellation of satellites in the late 1990s, the satellites' streaks were sometimes visible when sunlight struck their solar arrays or antennas at night.

Jud McCranie/Wikipedia

DUELING S

The companies leading the resurgent interest in supersonic travel have unique visions for how to normalize flight at speeds over Mach 1. Keith Button and Cat Hofacker tell the story.

BY KEITH BUTTON | buttonkeith@gmail.com and CAT HOFACKER | catherineh@aiaa.org

TRATEGIES

Aerion's red AS2 and Boom's Overture represent companies with different approaches to the potential market for supersonic aircraft.

Aerion and Boom

The clashing business strategies of Aerion and Boom Supersonic are visible in the marketing pitches for their proposed supersonic passenger jets.

Aerion, based in Nevada and partly owned by Boeing, promises on its website to break down the "barrier to family, love, adventure, and time well spent." Meanwhile, in Colorado, rival Boom asks business travelers to "imagine crossing the Atlantic, conducting business, and being home in time to tuck your kids into bed."

In short, for Aerion, the path toward commercially viable supersonic travel runs through the super wealthy, who today buy business jets for fun as much as business. Boom, by contrast, wants to start by introducing a supersonic design that airlines will buy for business-class customers.

The question is whose strategy has the best odds of making supersonic travel a reality — not just for business travelers or billionaires, but someday for all of us. If their manufacturing schedules are to be believed, by the mid-2020s, the first evidence will begin to roll in.

One point of consensus among the competitors is that the revolution will require persistence and patience by those who fund the endeavors and those who will regulate the aircraft for safety, noise and emissions.

Boeing's Eric Kaduce, director of the Boeing-Aerion venture, drew a parallel between this era and the 1950s. "When the 707 and the DC-8 came out, the range was shorter than a Super Constellation," he said at January's AIAA SciTech Forum, referring to Lockheed's famous propeller-driven airliner. The first jets were noisier and burned more fuel. "We could have regulated [jet flight] out of existence," he said. Instead, the 707 and DC-8 set the industry on a path toward modern airliners that are 70% quieter and that burn 70% to 80% less fuel. "I think it's time for us to do it again with supersonics," he said.

For Aerion, the starting point will be its 12- to 13-person, Mach 1.4 business jet, the AS2. Aerion plans to fly the first one in 2024 and deliver the first aircraft to customers in 2026.

Creating a supersonic business jet will be "a little bit of a lower-risk way of starting to build those regulatory pathways, those environmental pathways, and prove out the technology," Kaduce told the SciTech audience.

The third competitor

Spike Aerospace of Boston, the supersonic-jet company founded in 2013 by physicist-entrepreneur Vik Kachoria, last year adopted a "quiet strategy," which is one reason the company has shared little information of late, Kachoria tells me. Kachoria says he also had to step back from some of his duties last September through November to focus on an undisclosed health issue. Spike still plans to fly a two-thirds-scale supersonic jet in 2021 to demonstrate low-boom flight. Kachoria concedes the 2025 target date for flying a full-scale version will likely slip.

— KEITH BUTTON

As for Boom's schedule, the company is not saying when it plans to fly its one-third-scale demonstrator, the XB-1, but the company has targeted the mid-2020s for introduction of Overture, a supersonic jet that would carry 55 to 75 passengers, depending on how an airline chooses to configure it. These aircraft would have a range of 8,300 kilometers and cruise at Mach 2.2.

"Eventually, assuming this becomes mainstream, what you'll see is there'll be a family of airplanes with different ranges. And you'll use the right airplane for the right route," says Joe Wilding, Boom's chief technology officer.

Like Aerion, Boom executives think supersonic travel could one day become the norm. "We believe that, long-term, flying supersonic around the planet is going to be the only way to travel."

Environmental challenges

Over the last year or so, Aerion and Boom have embraced the need to address the sizable carbon footprints of their proposed supersonic aircraft.

At SciTech, Kaduce said Boeing will "work with the regulators and start working with the environmental community," so that "50 years from now, what we're talking about is: How do we go from Mach 5 to Mach 8, not how we go from 0.85 to 0.92."

Wilding of Boom says, "we're massive fans" of "synthetic fuels made from more carbon-neutral sources."

While climate change has seized center stage, it was the threat of noise pollution in the form of sonic booms that drove the businesses strategies that are playing out today.

The noise issue prompted Boom to focus on business-class airline travelers who often need to fly intercontinental across oceans. Once out over the sea, an Overture aircraft can accelerate past Mach 1.0 without running afoul of prohibitions around the world against supersonic overland flight, especially the decades-old FAA ban that helped doom the Concorde fleet.

During its formative years, Boom knew that NASA was making plans to clear a regulatory path for a new generation of supersonic passenger jets through what's now called the X-59 Low Boom Flight Demonstrator. Under construction by Lockheed Martin Skunk Works in California, the X-59 will be flown in U.S. airspace starting in 2023 to gather community responses to variations of its sonic thump. The FAA and regulators outside the U.S. would then decide just how quiet supersonic passenger jets need to be when flying supersonically over land. In the U.S., this survey data could end the prohibition that's been in place since 1973.

For Boom, the problem was the time all this would take. "We, as a company, decided we couldn't let our future and our schedule rest on something like that when it's completely out of our hands," says Wilding. "There'll probably be five, if not more, years of discussion around that before any kind of a general consensus comes out on how quiet is quiet enough."

Boom's schedule challenges have been great enough without waiting for the X-59 results. Engineers initially thought they could propel the XB-1 with a particular version of the General Electric J85 engine, but the desired version turned out to be unavailable. "We had to back up to a different variant with a little bit less thrust. We were able to work around that, but it very much was a delay to the program," Wilding says.

The XB-1 cockpit is bonded in Boom's hangar in Colorado.

Boom

▲ **The hangar at Boom** Supersonic headquarters in Colorado.

Boom

Exploiting the Mach cutoff

Aerion also is not waiting for the X-59 results, but it has gone in an entirely different direction on the noise question. Part of its business case will involve flying over land at a top speed of Mach 0.95, but the company also wants to convince the FAA and international regulators that an AS2 can fly faster than Mach 1 without creating a sonic boom that can be heard on the ground. How? By taking advantage of a phenomenon called the Mach cutoff.

Aerion's Gene Holloway, the company's chief sustainability officer, explains the strategy like this:

The cutoff point refers to the fact that, under the right combination of wind, altitude and speed, no sonic boom would be heard on the ground. By the numbers, the speed of sound — or Mach 1 — decreases as altitude increases, up until about 37,000 feet. If a plane is flying at 30,000 feet at 1,091 kph, which is Mach 1 at that altitude, then it won't create a sonic boom at sea level because the plane is not exceeding 1,225 kph — the speed of sound at sea level.

With the Mach cutoff concept, an airplane could fly at 30,000 feet at Mach 1.1, or 1,201 kph, and still not generate a sonic boom on the ground, assuming the ground is at sea level. By monitoring the temperature, tailwinds and headwinds, and the altitude of ground level along its flight path, an AS2 could fly at just above Mach 1 without creating sonic booms along the ground, Holloway says. It would sound like a subsonic commercial plane flying overhead.

"You're not going to have this major disruptive sound like a Concorde or a military jet; nothing like a space shuttle and certainly not like a SpaceX booster coming back," he explains.

Pilots flying over land under the Mach cutoff concept would want to avoid cruising at Mach 1 exactly, where drag is maximized, and aerodynamics are unsteady. The further away from Mach 1, faster or slower, the lower the drag. Over the ocean, AS2 will cruise at Mach 1.4, Holloway says.

Competing with today's air travel

Business travelers and the super-rich will be the first beneficiaries of their aircraft, but the supersonic pioneers see themselves as laying the foundation to someday bring supersonic flight to all of us.

Wilding predicts that supersonic aircraft will rival conventional aircraft on cost of travel and environmental sustainability.

"We think that's several generations of airplane and engine away, but we do think that's feasible within our lifetime," he told an audience at SciTech.

As for the competing strategies of Aerion and Boom, Wilding says there's another way to look at it.

"We're all helping each other indirectly or directly. We're pushing the idea forward. We're pushing the mainstream acceptance of this forward. We're training people. We're helping to influence organizations like AIAA to give more space for these discussions," he says. "We're big fans of everybody working in this space." ★

How movies inspire innovation

▲ Astronaut Samantha Cristoforetti of the European Space Agency tweeted this photo as a final salute to Star Treks' Leonard Nimoy when he died while she was serving as a flight engineer on the International Space Station in 2015. She wrote: "Of all the souls I have encountered, his was the most human. Thx @TheRealNimoy for bringing Spock to life for us."
NASA

A good movie or TV show can do more than transport us to another world for two hours. It can stimulate engineers and scientists to take on thorny questions that will propel their careers. A movie may even have encouraged one billionaire to launch a rocket company. Amir S. Gohardani takes a look at the symbiosis between fiction and facts.

BY AMIR S. GOHARDANI

The house lights dim. The silver screen lights up to the roaring sound of a piston engine sweeping away from us. At 9 o'clock, a Zeppelin is engaged in aerial bombardment as the Red Baron's Triplane suddenly appears out of nowhere with a climbing spin. Shock and awe, and within seconds we are catapulted into an aerial battle that unfolds at a pace matching our popcorn consumption. Then, in the turmoil between war and peace, it arrives: that one scene that the aeronautical engineers in the audience will deem as totally implausible. They will quietly roll their eyes and after the closing credits engage in an endless critique.

Welcome to the magic of the movies or, for that matter, TV and literature. The power of the story draws us in more than the validity of the depicted aerospace engineering concepts. Even if the technology doesn't exist or defies the laws of physics, it inspires new trains of thought aimed at bringing the impractical into the realm of the practical.

In an exemplary case, versions of "Scotty, beam me up," from the original "Star Trek" series have inspired millions, if not billions, to think about time and space travel. This is despite the implausibility, I presume, of ever beaming a person from one location to another — although human holograms come close.

Marrying imagination with unprecedented technical achievements is not new. In literature, Jules Verne, the French novelist whose many works have been dramatized, envisioned space travel in his novel "From the Earth to the Moon" published in 1865. Verne's literary work inspired me as a youngster growing up in Iran and, I would later learn, many before me, including pioneering American aviator Rear Adm. Richard Evelyn Byrd Jr. ; Yuri Gagarin, the first human to journey into outer space; Konstantin Tsiolkovsky, the Russian and Soviet rocket scientist; Wernher von Braun, the German and later American aerospace engineer and space architect; and Jack Parsons, the American rocket engineer and rocket propulsion researcher.

Words and images serve a larger purpose: They encourage out-of-the-box thinking.

Yet, there is much more at play. If one considers books and movies as tools for learning, then these mediums encourage out-of-the-box thinking, like the wake effects in a world unbounded by conventional reality. Technically minded readers or viewers are free to question the status quo. A holistic approach unfolds, meaning one in which the innovator honors none of the traditional boundaries among physics, chemistry, materials science, aerodynamics and other disciplines. The result is a new norm for how one should go about defining solutions to technical problems.

Of course, it's worth noting that efficient learning engages different senses, and in this regard, everybody does not learn in the same way. Examples are auditory learners (learning by listening), kinesthetic learners (learning by doing or through physical activities) and visual learners (learning by viewing graphs, charts, maps and diagrams). The breakdown of learning methods is complex and often includes mixed modalities and a variety of other unexplored factors.

When films were born in the 20th century, they strongly engaged the visual and auditory modes of learning, and so this new type of entertainment engaged a larger portion of the population than books alone. I acknowledge that books have always fueled readers' imaginations. Movies, however, add a touch of realism to that imagination and depict an animated example of an envisioned concept. Naturally, the secondary wave of imagination is then an alternative version of the envisioned concept. There are countless examples of the concept of time travel in literature. Samuel Madden's "Memoirs of the Twentieth Century" from 1733 dealt with a guardian angel traveling back in time. Later, countless authors, including Charles Dickens, Mark Twain and Isaac

I cannot have asked for a more glorious period in my life and a better source of inspiration than to emerge in an environment where imagination constantly squared off against the laws of physics and the realms of possibility.

Asimov, explored the concept. But the depiction of time travel in the Stargate sequence of "2001: A Space Odyssey" was an entirely new experience. This movie earned Stanley Kubrick 13 Academy Award nominations and one Oscar for special effects. Douglas Trumbull, the movie's special photographic effects supervisor, ingenuously depicted time and space travel with a mixture of colors and light. Among the viewers impacted by this sequence was filmmaker Steven Spielberg, who repeatedly watched the movie for its creative use of the visual medium.

There is little doubt that films and visual medium elements have societal impact. That said, the size of this impact, as for instance measured by an influencing indicator on a population in society, is debatable and this alone is the power of movies. The discussions about that depicted impossible scene or the series of events that unfolded contrary to what would happen on an aircraft or onboard a space station, in air or space, all lead us to further analysis of what we have witnessed. In this process, we make inquiries and even learn to find out what really is possible and how far a specific technology has been developed. We record, process, analyze and draw conclusions, constantly examining the technical areas before us.

I vividly remember reading Jules Verne's book series when I was 7 years old. Elements of these books and others were brought imaginatively to life through animated TV series and movies. One of the movies that I found especially appealing was 1951's "No Highway in the Sky," which is based on Nevil Shute's 1948 novel. In the movie, an aeronautical engineer predicts that a new model of the airplane would fail catastrophically and in a novel manner. The movie touched on the outer bounds of aircraft design, a topic that proved interesting to me as a child and still does today. Nevil Shute was, of course, an English novelist and aeronautical engineer, so his insightful perspectives assisted with painting a plausible storyline. A leap down memory lane brings me back to my room decorated with cards featuring aircraft and their technical performance data. Posters and television shows featuring various elements of aerospace technology were part of my world until the aircraft design process began in my mind. Ultimately, these series of steps were continuously improved by my father, an aeronautical professional. Looking back, I cannot have asked for a more glorious period in my life and a better source of inspiration than to emerge in an environment where imagination constantly squared off against the laws of physics and the realms of possibility.

Interestingly, many of those who currently spearhead efforts in the aerospace sector also have had their shares of inspiration. Jeff Bezos is a "Star Trek" fan, according to Christian Davenport's book "The Space Barons." And Bezos reportedly watched the movie "October Sky," about the amateur rocket exploits of Homer Hickham, in 1999 with science fiction author Neal Stephenson, who encouraged Bezos to follow his interest in starting a rocket company. One year later, Bezos founded Blue Origin.

As humans, our paths to our desires and dreams are shaped by our imaginations, perceptions and impressions. The influence of movies on society and the aerospace industry and workforce is notable. Next time that one impossible technical scene plays before your eyes, it is worthwhile to embrace those moments as a vehicle that adds momentum to the discussions for alternative technologies or encourages our minds to identify a myriad of pathways to making the impossible possible. ★

Amir S. Gohardani is an AIAA associate fellow and the chair of the institute's Society and Aerospace Technology Integration and Outreach Committee.

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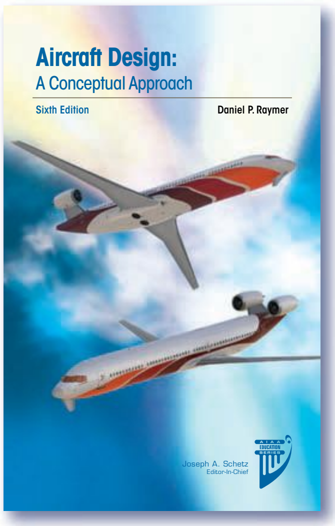

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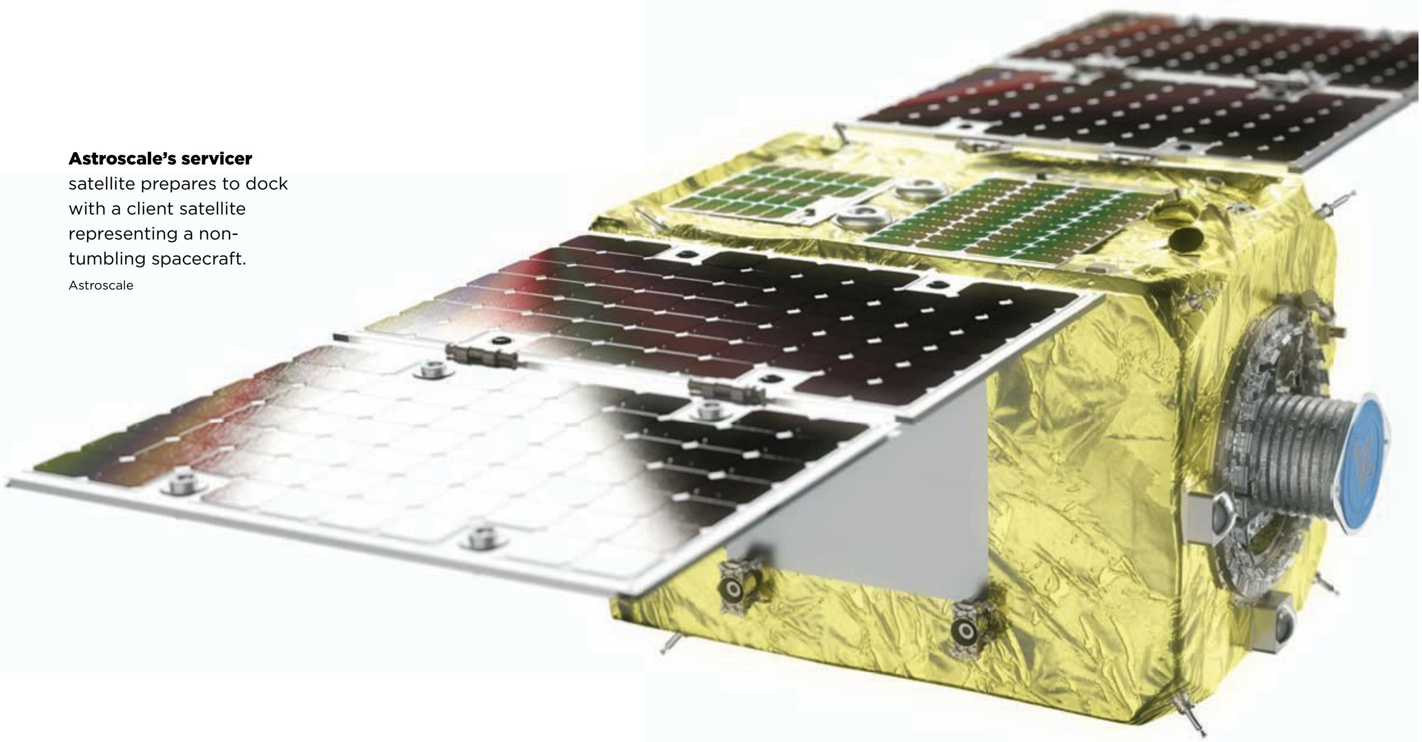
SHAPING THE FUTURE OF AEROSPACE

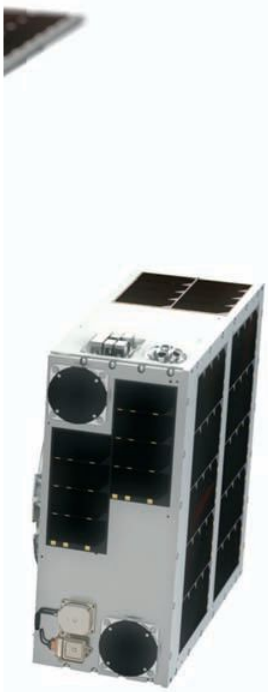


Astroscale's servicer satellite prepares to dock with a client satellite representing a non-tumbling spacecraft.
Astroscale

Debris sweeper

The large constellation builders are starting to launch their satellites now, despite a lack of consensus about how best to clear away worn-out or malfunctioning satellites. Enter Astroscale, a startup headquartered in Tokyo with offices in the United Kingdom, the United States and Singapore. The company is about to conduct an orbital demonstration of a magnetic cleanup technique. Astroscale's Jason Forshaw explains how the mission will work.

BY JASON FORSHAW



Current and future generations deserve an orbital environment that is free of dangerous debris. Achieving this sustainability will require a host of innovations on a global scale, including a reliable method for safely disposing of satellites that have reached the end of their lives. Sweeping space free of ghost spacecraft will open orbital slots for newcomers and reduce odds of collisions and debris that could, in the worst case, render much of low-Earth orbit useless for satellite operators and potentially disrupt services that people use in their everyday lives on Earth.

Estimates are that between 5% and 10% of satellites will end up failing in some manner.

Satellites that naturally reach the end of their lives — run out of power or fuel or have failed electrical or mechanical parts — become orbital debris. A particularly daunting challenge will be the many satellites that could be left tumbling in orbit.

Proving the feasibility of removing them from orbit with a magnetic capture system will be the challenge for our upcoming ELSA-d mission, short for End-of-Life Service by Astroscale-demonstration. ELSA-d's demonstration will be critical to the future of the space business, given that operators including OneWeb of London and SpaceX of California have begun launching large constellations for provision of internet services, putting potentially thousands of satellites into low-Earth orbit for communications. Vast constellations for Earth imaging and perhaps weather forecasting are likely to follow.

If the series of orbital maneuvers planned for ELSA-d go as well as we expect, future operators of large constellations could hire Astroscale to responsibly dispose of satellites by dragging them to lower altitudes and releasing them to burn up. In addition, Astroscale is talking to governments worldwide about removing old satellites and rocket bodies from space — this is known as "active debris removal" or ADR.

At our corporate headquarters in Tokyo, we are in the midst of testing the key elements of ELSA-d, our washing-machine-size servicer satellite and a smaller companion satellite called the client. These will be locked together during launch, and then separated in space to begin a series of ADR experiments. The satellites will be controlled from the National In-orbiting Servicing Centre, at the United Kingdom's Satellite Applications Catapult. Astroscale co-produced this servicing center with a specific focus on operating future ADR services. This center is in the Harwell space cluster outside London, near Astroscale's U.K. offices.

The most ambitious test for ELSA-d will be our attempt to stabilize the client after it has been commanded to tumble, as though it were an out-of-control satellite.

Astroscale

The servicer satellite is prepared for transportation from the Astroscale clean room to the Japan Aerospace Exploration Agency's Tsukuba Space Center for environmental testing.

A fully uncontrolled tumbling satellite has never been captured and stabilized before. The feat would mark a breakthrough for me and my colleagues at Astroscale, but even more importantly, for the space industry overall.

The challenge of docking with a tumbling satellite drove some difficult technical choices in the design of ELSA-d. As far as the capture mechanism goes, the technical literature shows a host of ideas ranging from nets to harpoons and robotic arms. We are unique in choosing to tap the power of magnetism. One of the core reasons we chose this solution is that tethered systems (such as nets and harpoons) are riskier in nature. With the magnetic capture system, docking and undocking can be repeated at a relatively slow and safe pace. A net or harpoon gets fired out, or deployed, at a very fast speed, and normally offers only one chance at capturing the client.

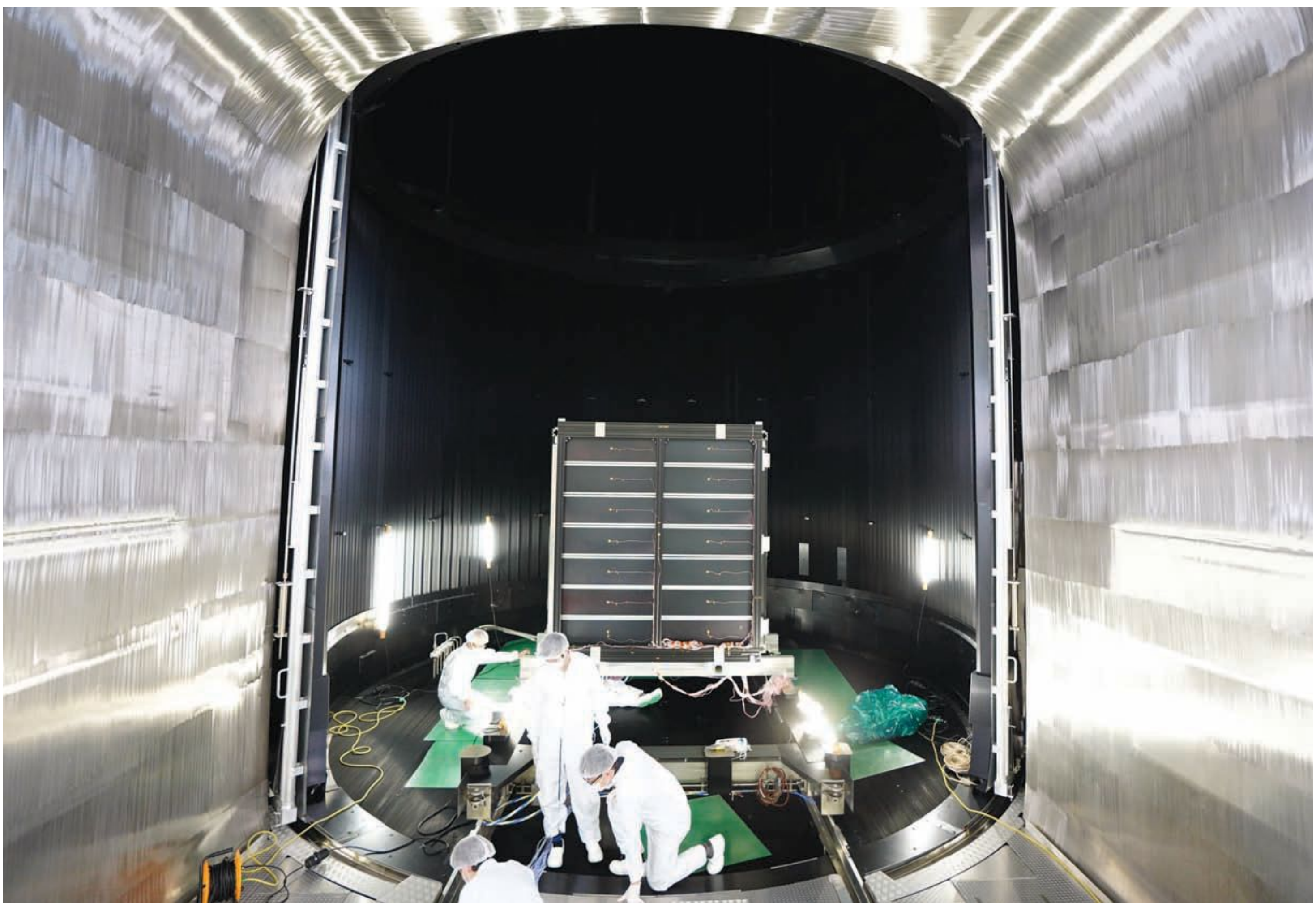
The servicer satellite is equipped with this magnetic capturing mechanism, which can extend and retract. The client has a docking plate or DP which is a ferromagnetic plate designed to be captured by the magnetic mechanism.

Astroscale makes these plates as do other manufacturers. Affixed to satellites during manufacturing, the plates are designed to accommodate a range of capture mechanisms, because the industry has not yet reached a consensus about the best method for disposing of satellites. Harpoons, in theory, could be fired into the plates, for instance, or robotic arms could grapple their raised fixtures. We are taking advantage of the simple concept of magnetism, where the magnet is attracted to the metal on the DP.

Recently large constellation operators have started to take interest in the DP concept. OneWeb, which has just begun launching its initial constellation of 648 satellites, confirms that each new satellite will have a grappling fixture that for our purposes will function as a DP.

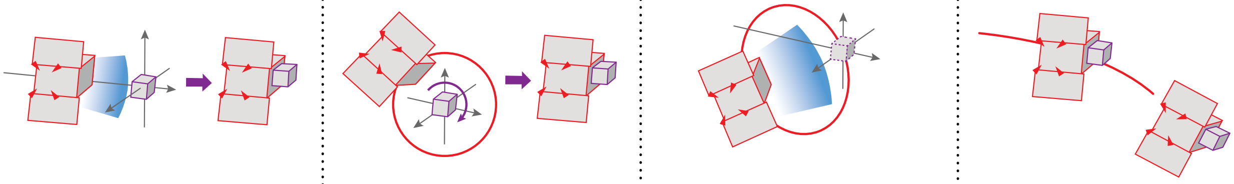
To begin each part of the ELSA-d mission, the client will separate from the servicer. As part of the capture demonstrations, the servicer will close in

Engineers prepare to test the demonstration spacecraft in the Thermal Vacuum Chamber at JAXA's Tsukuba Space Center.
Astroscale



DOCKING WITH DEBRIS

This year, Astroscale plans to conduct a 6- to 12-month orbital demonstration of its technique for removing old or malfunctioning satellites from orbit by capturing them with a magnet. To start each test, the larger satellite, the servicer, will separate from the client, which serves as a surrogate for a dead satellite equipped with a metal docking plate:



ONE CAPTURE WITHOUT TUMBLING

- Radars and lasers (represented by the blue) locate the client
- Servicer closes in with thrusters
- Magnet on servicer extends to gently meet docking plate, completing capture

TWO CAPTURE WITH TUMBLING

- Servicer sends images of client to ground
- Data sent to servicer, telling it how to maneuver with thrusters to face docking plate
- Servicer and client dance to maintain proper alignment, as magnet on servicer extends to complete the capture

THREE DIAGNOSIS DEMONSTRATIONS

- Servicer flies around client to inspect it with radars and lasers
- Servicer simulates approach to client without a docking plate
- In the final scenario, servicer loses client and must find it, then approach it and complete the final capture

FOUR DE-ORBIT AND CLOSEOUT

- Servicer maneuvers to reduce client altitude
- Client's remaining fuel is exhausted and avionics are turned off
- Servicer and client move to an uncontrolled orbit and burn up on reentry

Source: Astroscale

on the client and perform a complex series of maneuvers to align and settle with the client. The servicer is equipped with a range of sensors (including radar and lasers) to identify where the client is located. The cube-shaped servicer has eight chemical thrusters, one on each corner. They fire in a coordinated manner to perform the maneuvering. Once the servicer has closed to less than a meter, the servicer's capture mechanism extends and gently docks with the client.

We'll undertake this capture demonstration for both nontumbling and tumbling scenarios. These proximity rendezvous operations are incredibly challenging for a tumbling satellite. Algorithms must calculate how to adjust the attitude and motion of the servicer so that it matches the tumbling of the client as it approaches for the docking. The mission design and design of the guidance, navigation and control are complex for this type of mission and over 75 people are now working globally on this mission.

If the safety software on board judges that there is risk of collision, the servicer will abort to a safe distance. In addition, a controller in the operations room can abort a docking at any time.

On ELSA-d, we'll run the demonstrations during a period of six months to a year. As this mission is complex, we'll take it slowly and complete one demonstration before starting the next. We'll ensure that everything is in place for the next demonstration to start before proceeding. In each capture, the mechanism can push away the client to undock from it.

For the ELSA-d mission this year, we've chosen to mature these key technologies. Future operational versions of the servicer would carry a dead satellite to a lower altitude and release it to burn up in the atmosphere. The servicer would then steer itself to rendezvous with the next satellite to carry it to disposal orbit. These maneuvers would require the addition of an electric propulsion engine fueled normally by xenon. Such engines have a high specific impulse, meaning they are extremely fuel efficient. The trade-off is that these engines cannot raise or lower the altitude quickly.

Of course, avoiding accidental collisions will be paramount during the ELSA-d mission. Our goal is to mitigate debris, not add to it. In order for a satellite to be launched into orbit, it must receive a government license. The U.K. Space Agency licenses our mission and we have extended significant effort in designing our mission to be safe from an operational perspective — which is required in order to obtain a space license. ELSA-d's success will be a game changer, as once such rendezvous technologies have matured, new business segments, like in-orbit servicing, will emerge in the market.

Then we will be ready to do our part to create a sustainable orbital environment for future generations. ★

Jason Forshaw is the European research and development manager at Astroscale UK, an orbital debris removal company founded in 2013 with headquarters in Tokyo. He holds a Master of Science from Stanford University, a doctoral degree from the Surrey Space Centre at the University of Surrey, and is an AIAA senior member.

AIAA Bulletin

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AIAA Headquarters / 12700 Sunrise Valley Drive, Suite 200 / Reston, VA 20191-5807 / aiaa.org

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Calendar

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2020			
7–14 Mar*	2020 IEEE Aerospace Conference	Big Sky, MT (aeroconf.org)	
10–12 Mar*	23rd AIAA International Space Planes & Hypersonic Systems and Technologies Conference	Montréal, Québec, Canada	22 Aug 19
18 Mar	AIAA Congressional Visits Day	Washington, DC	
20 Mar–17 Apr	Fundamentals of Airplane Performance, Stability, Dynamics, & Control Online Short Course	Online (aiaa.org/events-learning/online-education)	
23–25 Mar*	55th 3AF Conference on Applied Aerodynamics — "Turbulent Flows in Aerodynamic Applications"	Poitiers, France (http://3af-aerodynamics2020.com)	18 Nov 19
24 Mar–12 May	Design of Modern Aircraft Structures Online Short Course	Online (aiaa.org/events-learning/online-education)	
27–28 Mar	Region III Student Conference	Columbus, OH	31 Jan 2020
27–28 Mar	Region IV Student Conference	Stillwater, OK	31 Jan 2020
28–29 Mar	Region VI Student Conference	Portland, OR	3 Feb 2020
2–3 Apr	Region V Student Conference	Wichita, KS	15 Feb 2020
6–7 Apr	Region II Student Conference	Tuscaloosa, AL	21 Feb 2020
16–19 Apr	AIAA Design/Build/Fly Competition	Wichita, KS (aiaa.org/dbf)	
21–22 Apr*	AIAA SOSTC Improving Space Operations Workshop 2020	Suitland, MD (https://isow.space.swri.edu)	
24–25 Apr	Region I Student Conference	State College, PA	16 Feb 2020
5–7 May	AIAA DEFENSE Forum	Laurel, MD	8 Oct 19
8 May	Trusted Autonomous Systems Course	Laurel, MD	
16 May*	The American Rocketry Challenge	The Plains, Virginia	
19 May	2020 AIAA Fellows Dinner	Crystal City, VA	
20 May	2020 AIAA Aerospace Spotlight Awards Gala	Washington, DC	
25–27 May*	27th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (elektropribor.spb.ru/en)	
13–14 Jun	1st AIAA CFD Transition Modeling Prediction Workshop	Reno, NV	
13–14 Jun	Design for Advanced Manufacturing: Aviation Lightweighting Course	Reno, NV	
13–14 Jun	Design of Electrified Propulsion Aircraft	Reno, NV	
13–14 Jun	Design of Unmanned Aircraft Systems Course	Reno, NV	

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.).

13–14 Jun	Hypersonic Flight Vehicle Design and Performance Analysis Course	Reno, NV	
13–14 Jun	Missile Aerodynamics Course	Reno, NV	
13–14 Jun	Practical Design Methods for Aircraft and Rotorcraft Flight Control for Manned and UAV Applications with Hands-on Training using CONDUIT® Course	Reno, NV	
14 Jun	2nd AIAA Workshop for Multifidelity Modeling in Support of Design & Uncertainty Quantification	Reno, NV	
14 Jun	Certification Workflows with Model-Based Design Course	Reno, NV	
14 Jun	Experimental Measurement Uncertainty for Engineers and Scientists Course	Reno, NV	
15–19 Jun	AIAA AVIATION Forum	Reno, NV	7 Nov 19
16–20 Jun*	Spaceport America Cup	Las Cruces, NM	
23–26 Jun*	ICNPAA 2020: Mathematical Problems in Engineering, Aerospace and Sciences	Prague, Czech Republic (icnpaa.com)	
9–13 Aug*	2020 AAS/AIAA Astrodynamics Specialist Conference	South Lake Tahoe, CA	10 Apr 2020
15–22 Aug*	43rd Scientific Assembly of the Committee on Space Research and Associated Events (COSPAR 2020)	Sydney, Australia (cospar2020.org)	14 Feb 20
22–23 Aug	5th AIAA Propulsion Aerodynamics Workshop (PAW05)	New Orleans, LA	
22–23 Aug	Liquid Rocket Engines: Emerging Technologies in Liquid Propulsion	New Orleans, LA	
24–26 Aug	AIAA Propulsion and Energy Forum	New Orleans, LA	11 Feb 20
14–18 Sep*	32nd Congress of the International Council of the Aeronautical Sciences	Shanghai, China (icas.org)	15 Jul 19
26–27 Sep*	CEAS-ASC Workshop 2019 on “Advanced Materials for Aeroacoustics”	Rome, Italy	
12–16 Oct*	71st International Astronautical Congress	Dubai, UAE (mbrsc.ae/iac2020)	
29 Oct–1 Nov*	37th International Communications Satellite Systems Conference (ICSSC 2019)	Okinawa, Japan (kaconf.org)	15 May 19
16–18 Nov	ASCEND Powered by AIAA	Las Vegas, NV (ascend.events)	17 Mar 20
2021			
11–15 Jan	AIAA SciTech Forum	Nashville, TN	8 Jun 20
31 May–2 Jun*	28th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (elektropribor.spb.ru/en)	
5–11 Jun	AIAA AVIATION Forum	Washington, DC	

● AIAA Continuing Education offerings

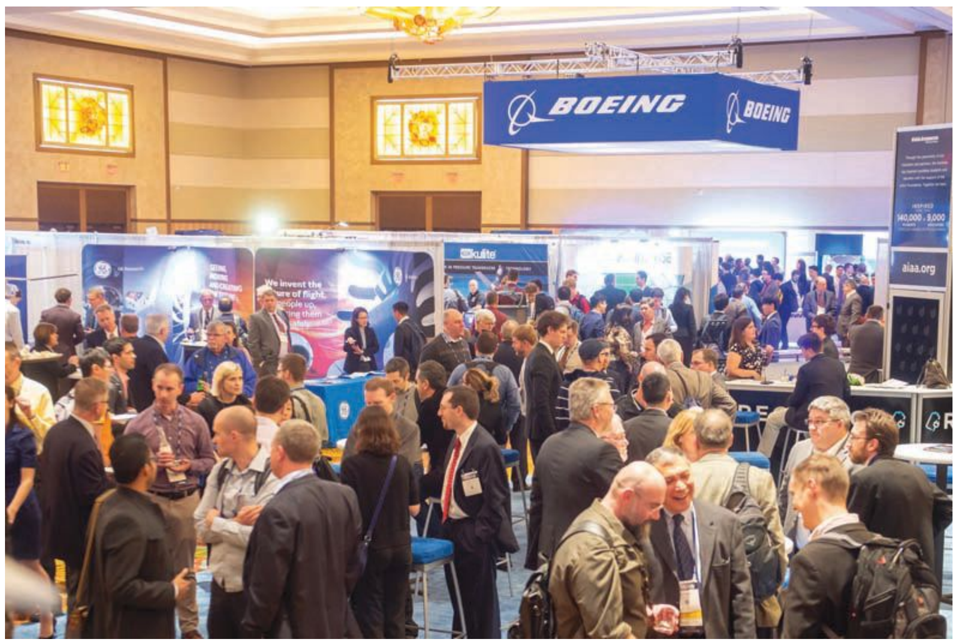
**Meetings cosponsored by AIAA. Cosponsorship forms can be found at aiaa.org/Co-SponsorshipOpportunities.*

SCITECH FORUM

Almost 5,000 attendees – representing 43 countries and 48 states plus Washington, DC, and Puerto Rico – gathered for the 2020 AIAA SciTech Forum, making it the most attended AIAA forum ever. Experts from industry, government and academia, as well as over 1,500 undergraduate and graduate students, participated in the incredibly energetic and successful forum in Orlando, FL, 6–10 January. The forum featured more than 2,300 presentations covering ground-breaking aerospace technical and scientific research.


SCITECH
FORUM


Women at SciTech Panel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aiaa.org


#aiaaSciTech
Faster


PANELIST
Col. David R. Scott,
USAF (ret.)
NASA Astronaut on Gemini VIII,
Apollo 9, and Apollo 15
NASA

CONGRATULATIONS, AIAA CLASS OF 2020 FELLOWS AND HONORARY FELLOWS

"The 2020 Class of AIAA Honorary Fellows and Fellows have earned the respect and gratitude of the aerospace community for their dedication, creativity and contribution to better understanding our world in terms of its limits and how we can push past those boundaries. They are the best minds in the industry. I congratulate them on this career accomplishment."

John Langford, AIAA President

2020 AIAA HONORARY FELLOWS

Robert D. Briskman
Telecommunications Engineering Consultants

Wes Bush
Northrop Grumman Corporation (retired)

Jason L. Speyer
University of California, Los Angeles

2020 AIAA FELLOWS

Holger Babinsky
University of Cambridge

John S. Baras
University of Maryland

Rodney D. W. Bowersox
Texas A&M University

Russell R. Boyce
University of New South Wales

Salvatore "Tory" Bruno
United Launch Alliance

Mark Campbell
Cornell University

Campbell D. Carter
U.S. Air Force Research Laboratory

Walter Engelund
NASA Headquarters

Hermann F. Fasel
University of Arizona

Hector Fenech
Eutelsat SA

Farhan Gandhi
Rensselaer Polytechnic Institute

Michael Gazarik
Ball Aerospace

Stanley Gustafson
Lockheed Martin Space

Steven J. Isakowitz
The Aerospace Corporation

Christopher T. Jones
Northrop Grumman Corporation (retired)

David Klaus
University of Colorado Boulder

Christophe Laux Ecole
CentraleSupélec, CNRS
University Paris Saclay

Joaquim R.R.A. Martins
University of Michigan

Beverley J. McKeon
California Institute of Technology

Daniel Mooney
Boeing Global Services

Scott A. Morton
U.S. Department of Defense

Nelson Pedreiro
Lockheed Martin Space

Christopher Pestak
Universities Space Research Association

Amy Pritchett
Pennsylvania State University

Dhanireddy R. Reddy
NASA Glenn Research Center

Donald O. Rockwell
Lehigh University

Suzanne Weaver Smith
University of Kentucky

Edgar G. Waggoner
NASA Headquarters

Michael M. Watkins
NASA Jet Propulsion Laboratory

AIAA FELLOWS AND HONORARY FELLOWS

You are cordially invited to join us at the Class of 2020 Induction Ceremony at the annual AIAA Fellows Dinner.

Tuesday, 19 May 2020
Hilton Crystal City, Arlington, Virginia

Reception: 1830 hrs
Dinner: 1930 hrs

For more Information and Registration, please visit
aiaa.org/2020-Fellows-Dinner
By invitation only – only AIAA Fellows and Honorary Fellows

AIAA
SHAPING THE FUTURE OF AEROSPACE

MAKING AN **IMPACT**

Middle Schoolers Impress with CubeSat Know-How

AIAA Palm Beach Section works with 5th-8th grade students

Attendees at the 2020 AIAA SciTech Forum got to see the next generation of aerospace leaders in action at the HUB in the Exposition Hall when 20 middle school students from The Weiss School presented the latest on their Wolverine CubeSat Development Team.

It's a great example of AIAA members mentoring students to introduce them to the vibrant field of aerospace from both a technical and public policy perspective. Kevin L. Simmons, founder of BLUECUBE Aerospace, a science educator at The Weiss School, and a member of the AIAA Palm Beach Section, and Shawna Christenson, the section's K-12 STEM Outreach officer, brought the students to AIAA SciTech.

The Weiss School also has a Public Policy Team that works directly with Congressman Brian Mast (R-FL), who recently reintroduced House Resolution 85, entitled "Wolverine CubeSats in Education." HR 85 aims to promote the use of CubeSats for educating the next-generation STEM workforce. Christenson led the students as they wrote the first draft of the language that became the resolution. Some of these students are expected to attend AIAA Congressional Visits Day in March, said Simmons, who won the 2017 Educator Achievement Award.

Simmons, **ksimmons@bluecubesat.com**, recommends that AIAA sections find educators in their area that will actively partner. "The best I can do as an educator is to create opportunities for my students to work with the very professionals that they want to emulate and eventually become. We also formed an AIAA high school section, and now have a joint annual banquet together with the students and professional members."

For more information about how to become involved with AIAA's educational outreach, please visit **aiaa.org/get-involved** or contact Merrie Scott, merries@aiaa.org.

13th AIAA Pacific Northwest Annual Technical Symposium

By Priscilla Khoury, 2019 AIAA Pacific Northwest Section Vice Chair

On 16 November, the 13th AIAA Pacific Northwest (PNW) Annual Technical Symposium was hosted at the Lynnwood Convention Center in Lynnwood, WA, and attracted about 233 attendees, which is a 30% increase from the previous year. This year we incorporated the use of a digital program powered by LineUpr.com, which included our traditional components such as plenary lectures, technical presentations, panel sessions, and speed mentoring. The student poster session, introduced last year, was also included and a mock interview workshop was added to the Rising Leader's (RL) session. The digital program user interface provided means of building one's agenda for the day by adding portions of the main program to a favorites list. Questions were submitted via the digital program interface for the panel sessions, which the moderator pulled for the Q&A portion of the discussion. Overall, both the technical and the interactive sessions received very positive feedback from our participants.

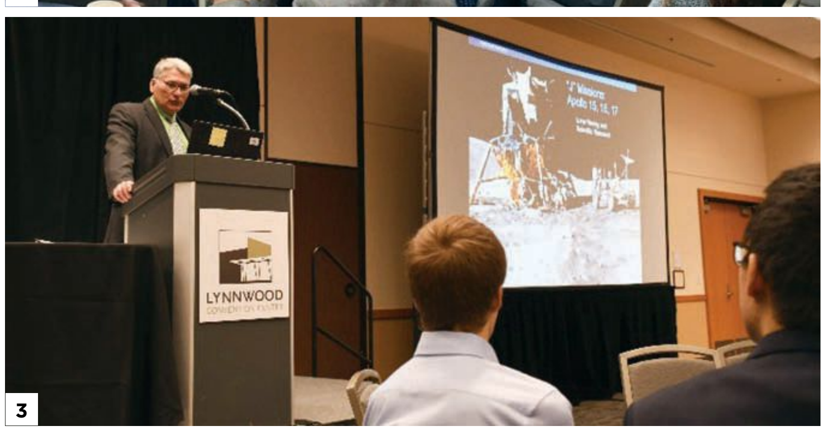
The symposium opened with a plenary presentation by Mike Lombardi, senior corporate historian for The Boeing Company, who shared an overview of the Apollo program through the often overlooked perspective of industry, specifically the contribution of The Boeing Company and its heritage companies. This year, as we celebrated the 50th anniversary of the first lunar landing, it was a great way to remind our audience about how our innovative contributions and hard work can go the distance.

Following the opening keynote, attendees had a choice between three parallel sessions, two of which were on the challenges and opportunities of accelerating electrified flight and emerging space propulsion technologies for deep space exploration, an overview of an accident investigation of LANSA flight 508, and a description of the Orb2 space station concept. The RL session was kicked off by Erika Wagner, Payload Sales Director at Blue Origin, who shared her personal perspective on finding one's way in their career development and lessons learned with young professionals and students. After a coffee break the RL session continued with a mock interview workshop led by Gina Baker, founder and CEO of Summit Connections, and Jason Slagle, director of Propulsion for the 787 Dreamliner and 747 at Boeing.

As the mock interview workshop was underway at the RL session, two panel discussions were held. One was on the three flavors of gliding in the Pacific Northwest and the other was on workforce development. The panels provided insightful discussion on different forms of gliding and different perspectives of what the current aviation workforce looks like as well as its future needs in the Pacific Northwest.

Transitioning into the afternoon, attendees were encouraged to network with each other and visit exhibitors in the concourse area of the convention center. Exhibitors included Aerojet Rocketdyne, Blue Origin, Boeing/Future of Flight, Jetoptera, Klinger IGI, Inc., Summit Connections, Crane Aerospace & Electronics, Alaska Airlines, LEAF/Lindbergh, PNW AIAA, PNW Soaring, Raisbeck, University of Washington,

1 Team of four getting ready to start the design challenge.
2 Erika Wagner, Blue Origin, gives the RL keynote.
3 Mike Lombardi, Boeing, gives the morning keynote.



Museum of Flight, PNAA, and the Center of Excellence for Aerospace & Advanced Manufacturing/Olympic College.

Our lunch keynote speaker Erik Lindbergh, Executive Chairman of VerdeGo Aero, talked about the birth of long distance aviation, to the creation of the personal spaceflight industry and an ambitious vision to jump-start a new short distance air travel industry with advances in distributed electric propulsion. Despite challenges that came along his journey, Erik advised our attendees to keep on going and to never give up.

Other afternoon lectures educated attendees on the Spalart-Allmaras turbulence model and our role in sustainability. A student poster session was held with contributions from the following schools and teams: Everett Community College Aviation Maintenance Program, Bellevue College, Embry-Riddle Aeronautical University, Portland State University, University of Washington undergraduate, and University of Washington Design, Build, Fly. Symposium attendees were encouraged to vote for their favorite and the winners were recognized later in the afternoon.

In the RL session young professionals had a chance to interact with industry experts and ask questions regarding their career choices, experiences, and anything else they were curious about.

A highlight of the symposium was the engineering design challenge, which provided a fun and interactive way to connect with others in teams. The goal was to construct a foam rocket designed to hit a designated target with the resources provided by satisfying a set of requirements. It also introduced our youngest attendees to the engineering design process.

The closing keynote speaker was Dr. Paul Bevilaqua, who played a leading role in creating the Joint Strike Fighter. He discussed how small engineering teams and rapid prototyping can achieve quick, quiet, quality products.

Reflecting back on another successful symposium we have already started preparations for next year's symposium to be held on Saturday, 7 November 2020, at the Green River College in Auburn, WA.

We could not have done all this without a fantastic team of volunteers, as well as our sponsors who year after year continue to show their commitment to the section membership: Ed Wells Partnership, The Boeing Company, Aerojet Rocketdyne Foundation, AeroTec, Klinger IGI, Inc., Tecplot, Base2 Solutions, Crane Aerospace and Electronics, Jetoptera, Paine Field Snohomish County Airport, Blue Origin, Verdego Aero, LineUpr, and Echodyne.

Every year we try to build on the past year's successes and expand the program with new items for variety, resulting in increased interest for the symposium. We would like to invite anyone interested in presenting, sponsoring, or contributing in any other way to take a look at **http://pnwaiaa.org/ts2019** or contact the symposium chair at **symposium@pnwaiaa.org**.

News

Young Professionals, Students, and Educator Conference

The AIAA Region I Young Professionals, Students, and Educator (YPSE) Conference was held for the first time in four years by the AIAA Mid-Atlantic Section on 15 November 2019 at the Kossiakoff Center at the Johns Hopkins University Applied Physics Laboratory in Laurel, MD. More than 160 young professionals (under age 35), graduate, undergraduate, and high school students were in attendance. Students came from 16 different universities and nearly 50 technical presentations were given on aerospace-related topics, including machine learning, robotics, aerodynamics, and navigation.

The event gave young professionals and students the opportunity to learn from each other about a large breadth of topics in the aerospace community, gaining knowledge in areas they may not have yet been exposed to. The keynote address featured former NASA astronaut and test pilot Pierre Thuot, who spoke about the three spacewalks he performed aboard the *Endeavour* shuttle in 1992. The conference also had several networking events, including an expo hall, networking activity, and happy hour, as well as an awards presentation.

The AIAA Mid-Atlantic Section will be hosting the 2020 YPSE Conference on **16 October**, at the Kossiakoff Center again. Please email **aiaa.midatlantic@gmail.com** for more details and check **https://engage.aiaa.org/midatlantic** for upcoming events.

Annual Business Meeting Notice

Notice is hereby given that the Annual Business Meeting of the American Institute of Aeronautics and Astronautics (AIAA) will be held at the Hilton Crystal City at Washington Reagan National Airport, Arlington, VA on Monday, 18 May 2020, at 1:00 PM.

Christopher Horton, AIAA Governance Secretary

The AIAA Legal Aspects of Aeronautics and Astronautics Outreach Committee held a dinner on 10 December, which included a panel on International Best Practices to Preserve the Outer Space Environment. AIAA Executive Director Dan Dumbacher participated in the panel.

On 22 January, the AIAA F.E. Newbold V/STOL Award was presented to Justin Paines at the International Powered Lift Conference in San Jose, CA. Mr. Paines was recognized for his leading role in the development of the Short Takeoff and Vertical Landing flight control system for the Joint Strike Fighter. L to R: Dr. Geoffrey Jeram, AIAA V/STOL Technical Committee Chair; Justin Paines, Chief Test Pilot, Joby Aviation; JoeBen Bevirt, Founder of Joby Aviation; and Mike Hirschberg, VFS Executive Director.

AIAA Council of Directors Meeting

Notice is hereby given that an AIAA Council of Directors Meeting will be held at the Hilton Crystal City at Washington Reagan National Airport, Arlington, VA on Tuesday, 19 May 2020, at 1:00 PM.

Christopher Horton, AIAA Governance Secretary

New Student Branches

AIAA is pleased to welcome eight new student branches, which were approved by the Board of Trustees in January. With these eight additions, AIAA now has 244 student branches. Please join us in welcoming these new branches!

Region I

American Public University System
(No Section Assignment)
FA: Marvine Hamner and Ed Albin
SBC: Scott Palmer

University of Tennessee-Chattanooga
(Tennessee Section)
FA: Kidambi Sreenivas and Trevor Elliott
SBC: Ashwyn Sam

University of North Carolina at Charlotte (Carolina Section)
FA: Karen Thorsett
SBC: Spencer Owen

Region II

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

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

Region III

University of Missouri at Kansas City
(Wisconsin Section)
FA: Travis Fields
SBC: Shawn Herrington

Region IV

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

Region VII

University of Canterbury
(International)
FA: Dan Zhao and Bruce Robertson
SBC: Matthew Furkert

FA = Faculty Advisor
SBC = Student Branch Chair

Correction: AIAA Student Branches, 2019–2020

Below are the AIAA student branches that were unintentionally left off the list published in the January issue on pages 55–58.

Region I

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

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

Region II

North Carolina State University
(Carolina)
FA: Jack Edwards
SBC: Paul Neil

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

Obituaries

AIAA Associate Fellow Isaacs Died in July 2019

Leslie T. Isaacs died on 27 July 2019, at age 92.

Isaacs served his country in the U.S. Naval Reserve, first Class Aviation Electronics Tech Mate. He was active duty from May 1945 to July 1946.

From 1946 to 1950 he attended the University of Tucson, Arizona graduating with a degree in Electrical Engineering. Isaacs was hired by Douglas Aircraft and worked for them in Long Beach for 42 years as an Electrical Engineer, retiring in 1992.

In 1990, he received an AIAA Special Service Citation from the Los Angeles/Orange County Sections.

AIAA Senior Member Blackaby Died in December 2019

James Blackaby passed away on 31 December at the age of 98.

In 1939 Blackaby attended the University of Oregon, before transferring to the University of Washington to pursue his interest in aerodynamics. He left the university to serve in the U.S. Army during World War II, but later returned to Seattle to finish his degree.

In 1947, he accepted a job with NACA at Ames Research. Blackaby began his career conducting research in the wind tunnels at Moffett Field. When Ames became part of NASA in 1958, he joined the Life Science Division. He was involved in the very earliest space flight research and technology for Project Mercury, Project Gemini, and the Apollo program, developing spacesuits and designing astronauts' life support systems. He holds a patent for the "Blackaby Backpack," a portable unit that enables astronauts to venture outside an orbiting spacecraft. In 1976 Blackaby retired from NASA.

AIAA Associate Fellow Bell Died in January

Robert (Bob) Bell died on 9 January.

Bell attended to Columbia University, but left to join the U.S. Air Force. He served six years in the Air Force, followed by two years in the reserves. He later received his mechanical engineering degree from the University of Colorado, and earned a master's degree equivalency in nuclear engineering.

Bell worked on many space development programs for Lockheed, Ball, Boeing, and SNC. He was a lead engineer on the transformational reusable launch vehicle demonstrator, the DC-X; a propulsion lead on the mighty Delta III launch vehicle; the propulsion lead for the Orion human spaceflight system; and most recently the Chief Engineer of NASA's Dream Chaser reusable spaceplane. Bell also directed the Air Force telescope site on Maui known as AMOS for several years for Boeing.

His expertise was valued, admired, and respected by his industry peers and his name was instated in the International Space Hall of Fame, along with his team members for their work on the DC-X rocket. Bell was known for his zealous dedication to ensuring the highest level of technical achievement to make sure the complex systems he dedicated his life to would work in space. He was a member of the AIAA Liquid Propulsion Technical Committee from 2015 to 2017.

AIAA Associate Fellow Westphal Died in February

Bill Westphal passed away on 1 February, at the age of 76.

Westphal earned his B.S. in Aeronautical and Astronautical Engineering from Ohio State University in 1969. He earned an M.S. in Aerospace Engineering and was a candidate for an Aerospace Engineering Ph.D. at the University of Cincinnati, an M.P.A. in Entrepreneurship and International Business at Kennesaw State University, and a Master's in Project Management from Penn State University. He was a Registered Professional Engineer in the State of Ohio.

In 1969 he joined the General Electric Aircraft Engine Department where he was the Lead Design Engineer for an Advanced Turbine Engine Gas Generator (ATEGG) Compressor and for a Joint Technology Demonstrator Engine (JTDE) Fan. The JTEG program successfully demonstrated application of a large internally bladed design of a high tip speed fan rotor an aircraft gas turbine engine.

In 1982 Westphal joined Rolls-Royce in Atlanta, GA, where he collaboratively partnered with leading U.S. companies to design, develop, and manufacture carbon-carbon, ceramic matrix, metal matrix and polymer matrix composites and high temperature protective coatings for gas turbine applications. He served as technical chair and later joined Roll-Royce Corporation in Indianapolis.

He is the inventor or co-inventor of a number of patents for the application of ceramic matrix composites for advanced turbine engines and the author or co-author of numerous technical papers.

Westphal was an active AIAA member, and participated on the Inlets, Nozzles, and Propulsion Systems Integration Technical Committee (2008-2019) and the Materials Technical Committee. He was also section vice chair and section chair in the early 1990s.

AIAA Honorary Fellow Grey, Founder of *Aerospace America*, Died in February

Dr. Jerry Grey, noted aerospace scientist and engineer, died on 4 February 2020, at age 93.

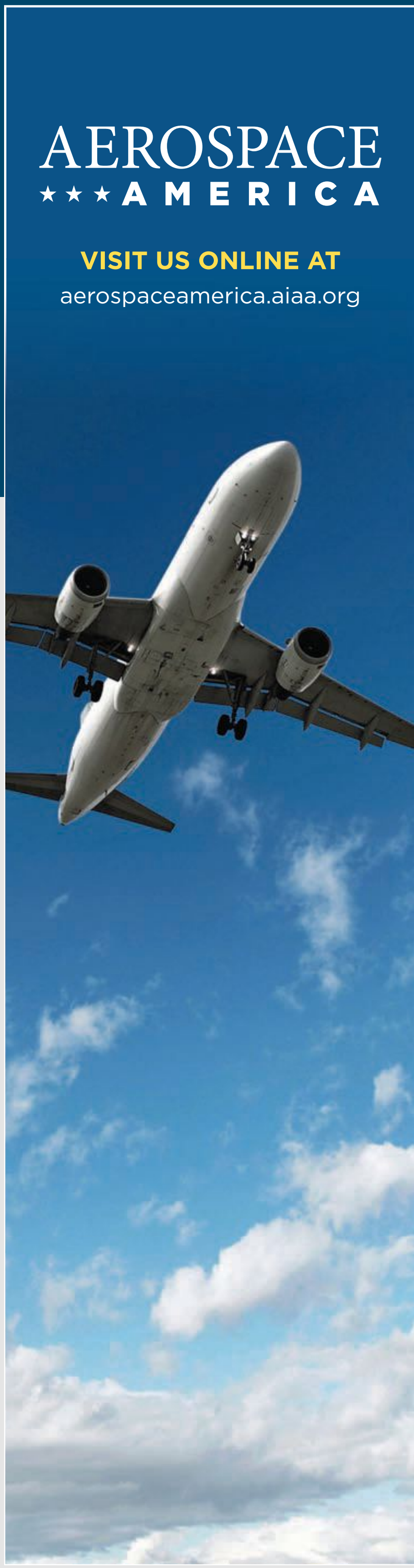
Dr. Grey held Bachelor's and Master's degrees from Cornell University and a Ph.D. from the California Institute of Technology. He was a professor of aerospace engineering at Princeton University for 55 years, where his research in rocket combustion instability was instrumental in assuring the reliability of the Redstone rocket that launched Alan Shepard, America's first astronaut, and of the Saturn launcher's giant F-1 rocket that placed the Apollo astronauts on the moon.

As Director of Princeton's Nuclear Propulsion Research Laboratory, he was a pioneer in the field of space nuclear propulsion and power. At Princeton, he created and taught the first university course on space nuclear powerplants. With the eminent scientist Arthur R. Kantrowitz, he was co-inventor of the Kantrowitz-Grey molecular beam source, which is the standard tool for research in this field.

Dr. Grey holds a dozen patents in high-temperature instrumentation, a field in which he was preeminent for years. He published over 400 technical and popular books and peer-reviewed papers covering broad areas of aerospace and energy science and technology, including the 1962 *Space Flight Report to the Nation* (edited by Jerry Grey and Vivian Grey). He consulted actively for a number of aerospace organizations and government agencies, including the U.S. Air Force, NASA, the U.S. Department of Energy, the Department of Transportation, the U.S. Congress's Office of Technology Assessment, the National Reconnaissance Office, Lockheed Martin Astronautics and its predecessor companies General Dynamics Space Systems (GDSS) and Martin Marietta, the Applied Solar Energy Corporation, the Universities Space Research Association, and NASA's and the Atomic Energy Commission's joint Space Nuclear Propulsion Office. It was on Dr. Grey's 1992 recommendation to the president of GDSS that the Russian RD-180 rocket engine was selected to power the Atlas-5 space launch vehicle.

Dr. Grey joined the American Rocket Society (ARS), one of AIAA's predecessor organizations, in 1948. Over the years he served ARS and AIAA in many capacities, including as a member of the AIAA Board and as Vice President of Publications. He founded *Aerospace America*, the primary monthly in the aerospace field, and was its publisher for over five years. As the founder of the AIAA's Public Policy program (he was a member of the committee from 1998 to 2017), Dr. Grey testified frequently at congressional hearings and represented the aerospace profession to the public media: television, radio, newspapers, and magazines, where he was quoted frequently on aerospace issues of national interest.

He also served as Vice President of the International Academy of Astronautics, and was President of the International Astronautical Federation. He was Deputy Secretary-General of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) and for 20 years wrote the annual report, "Highlights in Space Technology and Applications" for the UN's Committee on the Peaceful Uses of Outer Space. Dr. Grey was Chairman of the American Association of Engineering Societies' Coordinating Committee on Energy; a charter member of the Science Advisory Board of the NASA Institute for Advanced Concepts; and Chairman of the organizing committee that created the Center for Space Nuclear Research at the Idaho National Laboratory, which is operated by his client, the Universities Space Research Association. Dr. Grey was also elected a Fellow of Great Britain's Royal Aeronautical Society.



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JOB OPPORTUNITIES

The University of Texas Medical Branch at Galveston (UTMB Health) is recruiting two non-tenure track Associate Professors to join the faculty in the Department of Preventive Medicine and Population Health (PMPH). The mission of this department is to apply interdisciplinary expertise toward improving health and function and reducing health inequities across communities. The successful candidate will join an interdisciplinary faculty group that engage in research, clinical and community service as well as the teaching of graduate students, medical students and other health professions trainees.

(1) Clinical Associate Professor, Non-Tenure Track

- Clinical Responsibilities: Serving as the Medical Director of the Aerospace Medicine Center (the aerospace medicine clinic at UTMB).
- Educational Responsibilities: Serving as the Director for the medical school aerospace medicine track.
- Supports grants and contracts related to aviation and space medicine.

(2) Associate Professor of Aerospace Medicine

- The selected candidate will serve as the Associate Director of the Aerospace Medicine Residency Program and Combined Internal Medicine/Aerospace Medicine Residency Program.
- Clinical responsibilities include conducting pilot aviation medical examinations, spaceflight participant medical evaluations and more.
- Support grants and contracts related to aviation and space medicine.

Candidate Requirements:

- M.D., D.O., M.P.H. or equivalent degree.
- Board certification in a clinical medicine discipline such as Internal Medicine, Family Medicine, Emergency Medicine.
- Board certification or eligibility by the American Board of Preventive Medicine (for Aerospace).
- Texas Medical License or ability to obtain such license within 3 months of start.
- Minimum of 5 years of experience in practice of Aviation or Occupational Medicine preferred.

Income Package: Salary will be commensurate with qualifications, experience and educational background. In addition, UTMB offers a superior benefits package, an excellent retirement program, a relocation allowance as well as other potential incentives.

Living in communities served by UTMB Health: Please click on or paste the below link to your internet browser to learn more about the various communities in and around the UTMB service area: **www.utmb.edu/utmbliving**

For more information, please submit a detailed Cover letter and updated Curriculum Vitae (CV) to, Skott Harrington at: saharrin@utmb.edu

UTMB Health strives to provide equal opportunity employment without regard to race, color, national origin, sex, age, religion, disability, sexual orientation, gender identity or expression, genetic information or veteran status. As a VEVRAA Federal Contractor, UTMB Health takes affirmative action to hire and advance women, minorities, protected veterans and individuals with disabilities.

utmb.edu The University of Texas Medical Branch | Member, Texas Medical Center

1920

March 27 A Sperry gyro-stabilized automatic pilot system undergoes tests on a Curtiss F5L aircraft at the Naval Air Station at Hampton Roads, Virginia. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 11.

March 31 French pilot Maj. Joseph Vuillemin and his observer, Lt. Chalus, complete what is perhaps the first flight across the Sahara, 5,600 kilometers. They started from Algiers on Feb. 6 and flew by stages to Dakar. **Flight**, April 15, 1920, p. 430.

March 31 The slotted wings of British aircraft designer and builder Frederick Handley Page are flown for the first time on a full-scale airplane, a modified DH.9, according to an announcement. The slots help prevent stalls while flying at low speeds. Gustav Lachmann of Germany claims prior credit with his 1918 patent and says a model was made and tested in 1917. Charles H. Gibbs-Smith, **Aviation**, pp. 192, 181, 248; C.H. Barnes, **Handley Page Aircraft Since 1907**, pp. 211.

1945

March 7 The tandem-rotor XHRP-X transport helicopter makes its first flight at Sharon Hill, Pennsylvania, with pilot and designer Frank Piasecki and co-pilot George Towson. **United States Naval Aviation, 1910-1980**, p. 140.

March 8 The Navy's Gorgon air-to-air missile makes its first powered test flight from a Consolidated PBY-5A off Cape May, New Jersey. Powered by a Reaction Motors 1,500 newton-thrust (350 pounds) rocket engine, the missile reaches an estimated 885 kph. **United States Naval Aviation, 1910-1980**, p. 140.

March 9 The U.S. 20th Air Force attacks Tokyo with incendiaries at low attitude rather than high explosives from high altitude, marking a change in the strategic bombing campaign against Japan. Because Tokyo and most of Japan's cities are made of wood, 279 Boeing B-29 Superfortresses drop 1,500 metric tons of incendiary bombs, setting fire to the city and destroying 41 square kilometers in the ensuing firestorm. An estimated 100,000 people die. David Baker, **Flight and Flying: A Chronology**, p. 301.

March 14 A British Royal Air Force Avro Lancaster bomber piloted by Squadron Leader C.C. Calder of the 617th Squadron drops the first 10,000 kilogram (22,000 pound) "Grand Slam" bomb, destroying the Bielefeld Viaduct in Germany. Although it misses its target, the bomb's explosion destroys a 91-meter section, cutting the railway line from Hanover to Hamm. A.J. Jackson, **Avro Aircraft Since 1908**, p. 360.

March 16-17 In the heaviest incendiary attack by Americans on Japan, 307 B-29s strike Kobe, bombing from 5,000 to 9,500 feet and burning about one-fifth of the city. K.C. Carter and R. Mueller, compilers, **The Army Air Forces in World War II**, p. 600.

March 18 The U.S. Navy's Douglas XBT2D-1 Skyraider single-seat carrier-based dive-bomber/torpedo-bomber (later designated the A-1/AD) flies for the first time. Although it is the first aircraft of this type, it becomes operational too late to be flown in combat during World War II. U.S. military pilots fly it during the Korean and Vietnam wars. Rene Francillon, **McDonnell Douglas Aircraft Since 1920**, pp. 384-388.

March 20-21 A British Royal Air Force de Havilland Mosquito Mk XXX shoots down a Luftwaffe Junkers Ju 188 bomber as Germany makes its last attack on England by piloted aircraft. Since the first Luftwaffe attack on Britain, 51,500 civilians have been killed by these raids and 61,000 injured. David Baker, **Flight and Flying: A Chronology**, pp. 301-302.

March 21 Eighteen British Royal Air Force Mosquito Mk VIs, escorted by 31 Mustang P-51D fighters, bomb Gestapo headquarters in Copenhagen, killing about 100 Gestapo staff and destroying Germany's archives of the Resistance. RAF fighters also mistakenly bomb a school, killing 86 children and 18 adults, most of them nuns. Poul Grooss, **The Naval War in the Baltic, 1939-1945**, p. 307.

March 27 The final V-2 rocket fired against England hits Orpington in Kent. Some 1,115 of the rockets have fallen in Britain, killing 2,700 people and and injuring 6,500 since September 1944. F.I. Ordway III and M.R. Sharpe, **The Rocket Team**, pp. 200-201, 245.

March 29 Germany fires the final V-2 of the war. The following day Heinrich Himmler, chief of the German armed forces, will order Germany's V-2 rocket troops to be released from their units and to join the provisional army group of Gen. Gunther Blumentritt. F.I. Ordway III and M.R. Sharpe, **The Rocket Team**, pp. 200-201.

During March 1945
The U.S. War Department initiates Operation Overcast to recruit German rocket scientists. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 50.

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1970

March 7 An array of spacecraft in deep space, satellites, sounding rockets and ground instruments collect data for a study of the 1970 solar eclipse and its effects on the Earth's atmosphere and ionosphere. The National Science Foundation directs the project with participation by NASA, the U.S. military, industry and university investigators, and the governments of Canada and Mexico. NASA, **Aeronautics and Astronautics, 1970**, pp. 77-82; **Aviation Week**, March 16, 1970, p. 16.

March 10 The French-German Dial scientific satellite launches on a French Diamant-B rocket from the French Centre National d'Études Spatiales, or CNES, site at the Guinea Space Center in Kourou, French Guiana. This launch marks the operational start of the French space center and the first test of the three-stage configuration of the Diamant. **Chicago Tribune**, March 11, 1970; **Aviation Week**, April 6, 1970, pp. 61-62.

March 10 Pan American World Airways inaugurates its Boeing 747 service between Los Angeles and Honolulu and Tokyo. **Aviation Week**, March 16, 1970, p. 23.

March 10 Lufthansa German airlines becomes the first non-U.S. airline to receive a Boeing 747. The aircraft arrives at Lufthansa's training facility in Tucson, Arizona, following ceremonies at Boeing's plant in Seattle. **Aviation Week**, March 16, 1970, p. 23.

March 13 Wernher von Braun, former director of NASA's Marshall Space Flight Center in Huntsville, Alabama, is sworn in by NASA Administrator Thomas O. Paine as the NASA deputy associate administrator for planning. NASA, **Aeronautics and Astronautics, 1970**, pp. 88-89.

March 13 The Harmon International Aviation and Space Trophy is presented by U.S. Vice President Spiro Agnew to U.S. Air Force Maj. Jerauld Gentry for a "brilliant piloting feat" while testing NASA's HL10 lifting body and to Apollo 8 astronauts Frank Borman, William Anders and James Lovell for the first crewed flight around the moon in December 1968. NASA, **Aeronautics and Astronautics, 1970**, pp. 88-89.

March 13 A hospital in Sydney, Australia, reports that it is keeping infants warm with high-heat-retention blankets made of a material used in astronaut spacesuits. **Chicago Tribune**, March 16, 1970.

March 15 A full-size mock-up of two Soviet Soyuz spacecraft, described as "the world's first space station," is one of the major highlights on exhibit at Japan's Expo '70 as it opens in Osaka. Also highly popular is a moon rock brought to Earth by Apollo 12 astronauts. The rock attracts 8,000 visitors per hour in the U.S. exhibit. **Aviation Week,** April 27, 1970, pp. 70-71; **New York Times**, March 16, 1970.

March 18 Apollo 11 astronauts Neil Armstrong, Buzz Aldrin and Michael Collins receive the National Space Club's Robert H. Goddard Memorial Trophy at the 13th annual Goddard Memorial Dinner in Washington, D.C., for their historic flight to the moon. Other awards include the Goddard Historical Essay Award shared by John M. Logsdon of Catholic University and Frank H. Winter of the National Air and Space Museum. NASA, **Aeronautics and Astronautics, 1970**, p. 94.

March 19 The U.S. Air Force's X-24A lifting body, piloted by Maj. Gerauld Gentry, completes its first powered flight after the X-24's release from a B-52 carrier aircraft. The X-24 is equipped with an XLR-11 rocket engine built by Reaction Motors Division of Thiokol Chemical Corp. NASA, **Aeronautics and Astronautics, 1970**, pp. 94-95.

March 31 Explorer 1, the United States' first satellite, reenters the atmosphere and burns up south of Easter Island in the Pacific Ocean. The satellite launched on a Jupiter-C rocket on Jan. 31, 1958. **Aviation Week**, April 8, 1970, p. 26.

1995

March 2 Space shuttle Endeavour lifts off from Cape Canaveral on a 17-day mission that will include astronauts testing three ultraviolet telescopes on the Astron 2 platform. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 724.

March 14 Norman Thagard becomes the first American astronaut to fly aboard a Russian spacecraft, the Soyuz TM-21. He and fellow crew members dock with the Russian Mir space station, returning to Earth March 22. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 724.

GAURAV BHATIA, 34

Principal engineer at Hughes Network Systems

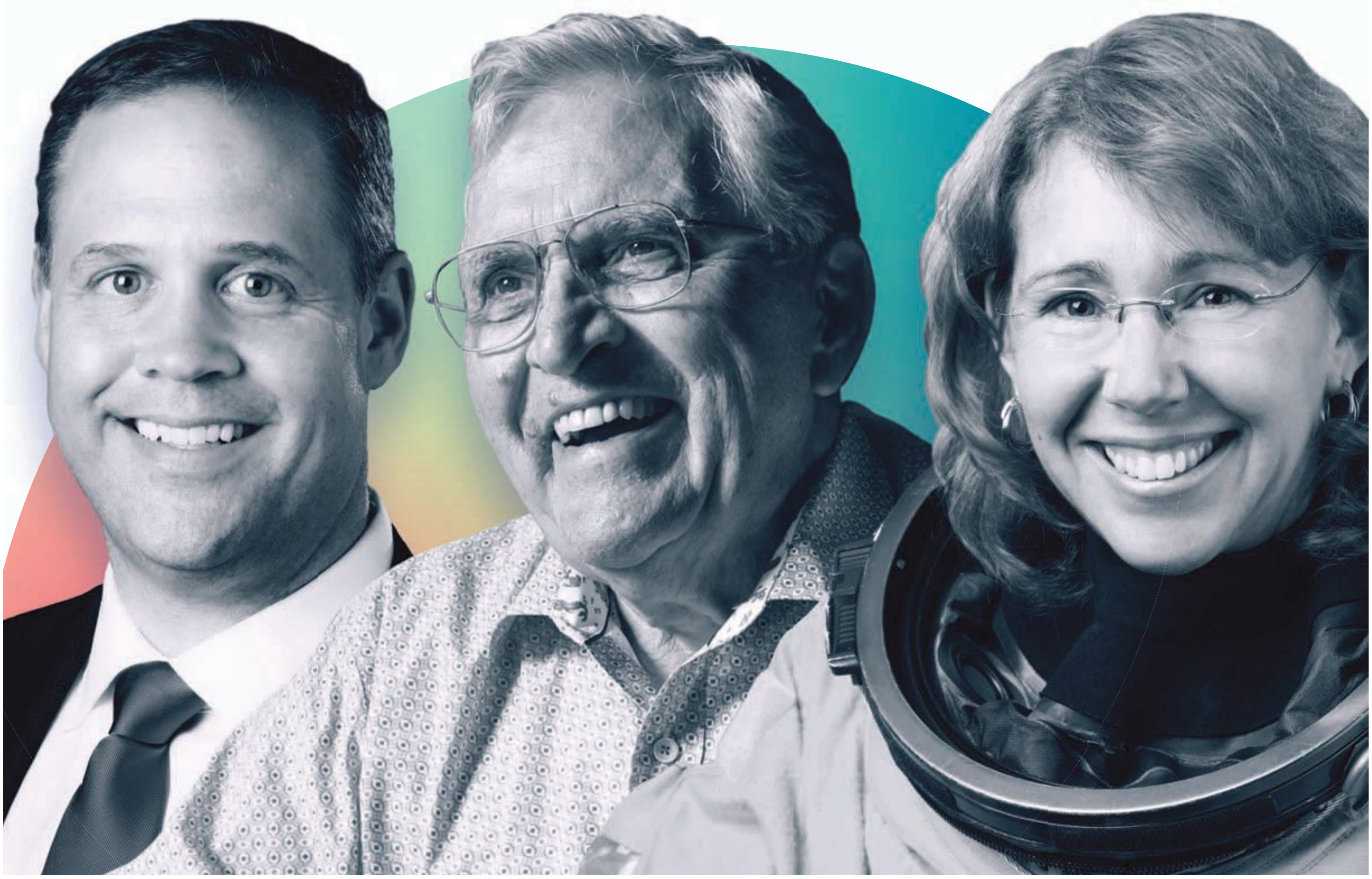
As a boy in India, Gaurav Bhatia was inspired to pursue engineering by his father, Ajay Kumar Bhatia, a metallurgical engineer, who read the encyclopedia with him, patiently explaining scientific and technical concepts. When his father brought work home and on Bring Your Child to Work days, Gaurav got a glimpse of his father's work creating lightweight, corrosion-resistant materials for Indian Space Research Organization launch vehicles. Gaurav Bhatia attended college in his hometown of Hyderabad, India, before earning a master's degree. Bhatia now helps develop satellite modems for Hughes Network Systems in Maryland.

Landing a job ▶ As a metallurgical engineer, my father had to overcome many challenges throughout his career. His achievements and fearless approach to solving difficult problems instilled in me a passion for engineering. For example, my father developed alloys that combine titanium with other chemical elements for the cryogenic engines and payloads of Geosynchronous Satellite Launch Vehicle missions like Chandrayaan [India's first lunar probe]. I received my bachelor's degree in electronics and communication engineering from Jawaharlal Nehru Technological University and went on to pursue my master's degree. During the final semester at Villanova University, I was hired by Hughes Network Systems in Maryland during the College Career Fair.

From design to verification and testing ▶ I am a firmware lead engineer in the Satellite Communications Modem design team at Hughes, where I work on FPGA/SOC [field-programmable gate arrays/system on a chip]-based hardware platforms to develop the next-generation high-throughput satellite modems. I contribute to the design by applying concepts from digital communications and signal processing, forward error correction coding and computer architecture. The day-to-day work involves using software tools and programming languages to verify these modems work as intended. I work closely with team members to evaluate new ideas, implementation detail and testing strategies. I also mentor junior members of our team. The modems my team develops power satellite communications for people and businesses around the world.

Space in 2050 ▶ Since data consumption is increasing worldwide, satellite internet will play an even bigger role in bringing high-speed connectivity to the unconnected and will become a more viable alternative for those in cities and suburbs. The aviation industry will also become a big source of growth for this market. With so many companies and countries setting aggressive goals for space exploration, a new space race has begun. By 2050, I expect some humans to be permanently living on the moon and at least a few to have touched down on Mars. While the technical challenges for this space exploration are tremendous, it opens doors to businesses. Take the internet; it is such a big part of our lives now that I imagine any human inhabitants of these planets or moons would like to be tethered socially and emotionally to Mother Earth. The trunking of data between Earth and these planets is a business opportunity in itself. ★

BY DEBRA WERNER | werner.debra@gmail.com



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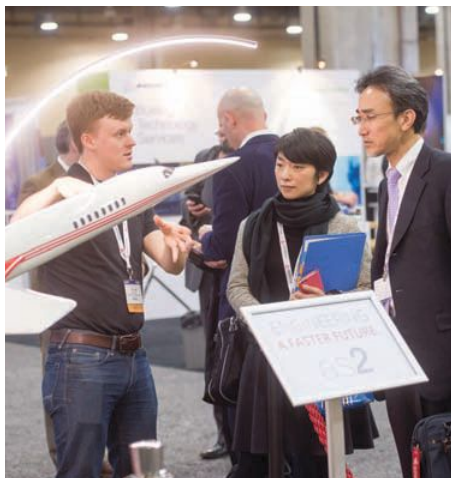

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